02.2024

NATIONAL GEOGRAPHIC

THE GLASS AGE

HOW CUTTING-EDGE TECHNOLOGY IS HELPING THIS ANCIENT MATERIAL RESHAPE OUR FUTURE

ROLEX AND NATIONAL GEOGRAPHIC
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MOUNTAIN GUIDE

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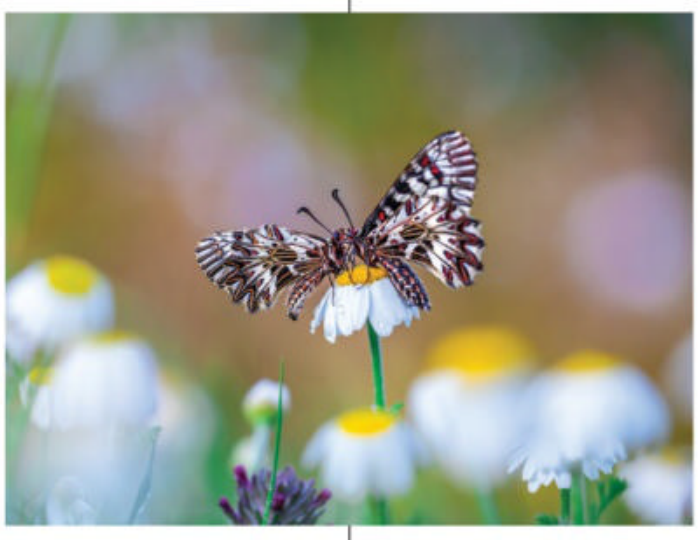
At the Corning company in upstate New York, a sheet of glass curls like a piece of paper, one of many innovations being made by researchers.
CHRISTOPHER PAYNE

PROOF



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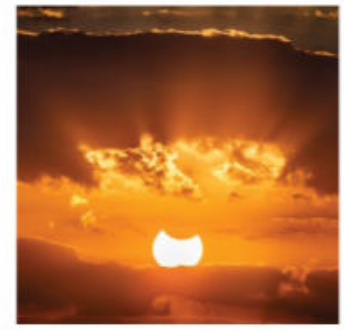

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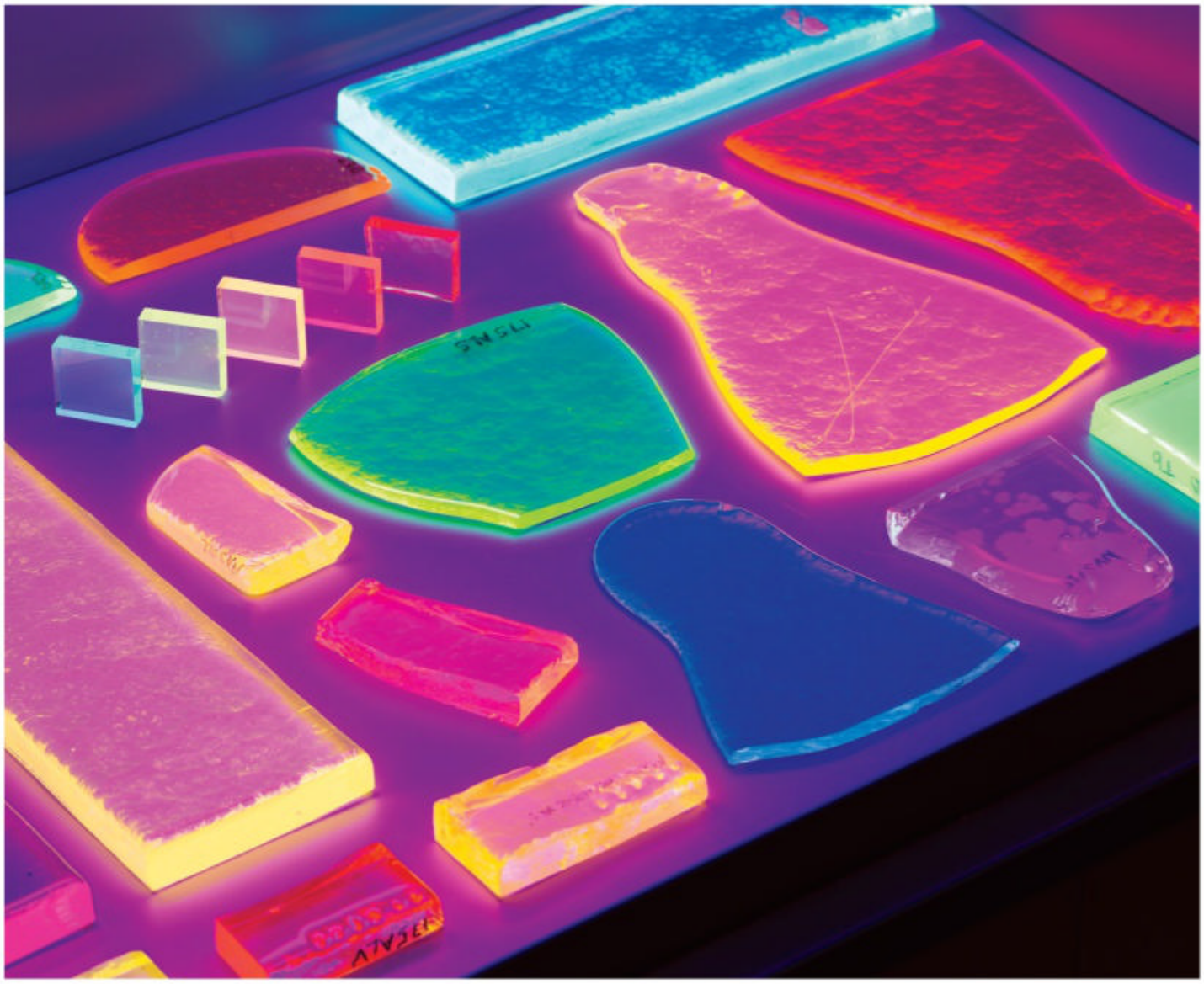


BY **NATHAN LUMP** PHOTOGRAPH BY **CHRISTOPHER PAYNE**

HUMAN INGENUITY IS a beautiful thing, and the subject of this month's cover story is a case in point. It's believed that we figured out how to make glass about 4,500 years ago, perhaps during the production of ceramic or metal, when the right combination of silica, soda ash, and limestone happened to come together and reach the temperature necessary to transform. An accident was decoded and mastered, and glass became an indispensable part of our lives.

In the millennia since, of course, our use of glass has continued to evolve. What started as beads, trinkets, vials, and bowls turned into windows and eyeglasses and mirrors—and then into telescopes, cameras, televisions, and the smartphone screens we all frequently tap on. Today what's exciting is how cutting-edge technology is powering our ability to shape and use glass in entirely new ways, now and in the foreseeable future, from bioglass that can fuse with bones and regenerate cartilage to windows that can harness solar energy to glass computer chips that can process information via light.

Our story is a reminder that great advances can come from refining something that's been known for a long, long time, when the ever inventive human mind is applied to it.

We've got other fascinating stories in these pages: how harp seals and their newborn pups are responding to climate change, a medical team that offers families a different way to treat children with incurable illnesses, the diversity of life supported by ephemeral woodland pools, and more.

We hope you enjoy the issue.

Ultraviolet light reveals different compositions of glass in a laboratory at Corning. The company, based in upstate New York, is experimenting with new recipes and methods to create glass that can function in astonishing ways.

Christopher Payne
Trained in architecture, Payne took a 10-year photographic journey into the world of manufacturing for his latest book, *Made in America*. His images have also appeared in exhibits in the U.S. and Europe and in outlets including CNN, the *New Yorker,* and the *New York Times Magazine*. **Page 34**

Jennifer Hayes
The biologist, author, and photographer has spent over 11,000 hours underwater, often collaborating with her partner, David Doubilet. For the July 2023 issue, they captured shark rewilding in Indonesia. Her work has been featured on NPR, CNN, National Geographic, and *Good Morning America*. **Page 122**

Susan Hand Shetterly
From her house in coastal Maine, Shetterly has written about wildlife and wildlands for the *Maine Times, Audubon* magazine, and others. Her books include *Settled in the Wild, Seaweed Chronicles,* and *Notes on the Landscape of Home,* which won a New England Society award. **Page 64**

NATIONAL GEOGRAPHIC EXPLORERS

These contributors have received funding from the National Geographic Society, which is committed to illuminating and protecting the wonder of our world.

Lynn Johnson
"It's a privilege to tell someone's story," Johnson says. With her camera and her compassion, she tackles challenging subjects that often reveal "the heroic nature of humanity." She was a Pulitzer Prize finalist for her work on *National Geographic*'s Gender Issue and received the National Geographic Society's 2019 Eliza Scidmore Award for Outstanding Science Media, in part for her cover story on a groundbreaking face transplant. An Explorer since 2017, Johnson is based in Pittsburgh but spends most of her time on the road. **Page 84**

Tim Laman
A field biologist, wildlife photographer, and filmmaker, Laman—shown here in a treetop blind in Borneo—documents rare and at-risk animals in tropical rainforests. His pioneering research in Borneo's tree canopy led to his first *National Geographic* feature story, in 1997. Mixing science with photography offers "the best of both worlds," he says. An Explorer since 1991, Laman co-founded the Birds-of-Paradise Project at the Cornell Lab of Ornithology and has earned many awards, including Wildlife Photographer of the Year from London's Natural History Museum. **Page 98**

PHOTOS (CLOCKWISE FROM TOP LEFT): KELLY GRIDER; ANNIE O'NEILL; TIM LAMAN; NINA CROCKER; DAVID DOUBILET

PROOF

NATIONAL GEOGRAPHIC

VOL. 245 NO. 2

A REAL BUG'S LIFE

In Bulgaria's western Balkan Mountains, a flower crab spider matches a spring pheasant's-eye bloom in a color-change process that takes a few days. The arachnid is an ambush predator: It doesn't build webs but lies in wait to pounce on its prey.

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

PHOTOGRAPHS BY
GEORGI GEORGIEV

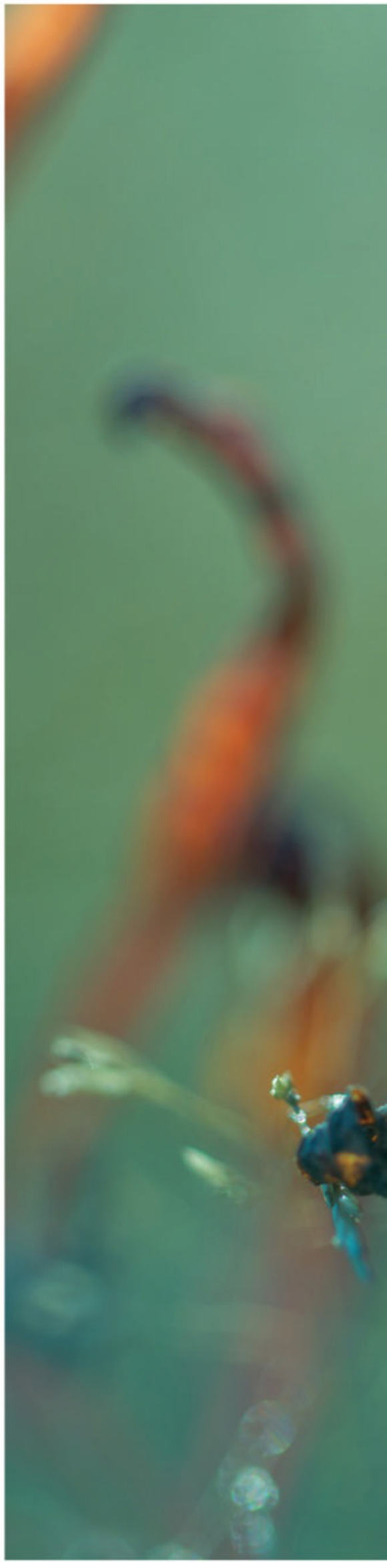
A photographer with a passion for small creatures gets up close with the diminutive and enchanting worlds of insects.

IT'S SPRINGTIME in the Balkan Mountains, and in a lush expanse, Bulgarian photographer Georgi Georgiev has his lens focused on something tiny. A yellow spider hides behind a yellow blossom, waiting for a meal. Their twin lemon hues aren't a coincidence—the flower crab spider is skilled at camouflage, blending into its surroundings to stealthily snatch prey. Georgiev clicks the shutter.

Georgiev's photography captures the rich lives of some of the planet's smallest inhabitants. In one image, an ant climbs a steep mound of dirt. In another, a ladybug drinks water from a dewdrop on a long blade of grass. "The smaller they are, the more hidden and interesting their world is to me," Georgiev says. He is always noticing something new: Most insects are not timid around his camera when they're mating or feeding. And on humid mornings, dew clings to the wings of butterflies, weighing them down and allowing Georgiev to get close.

"You can see their behavior, how they feed, how they reproduce, how they survive," he says. He's watched mating dragonflies form the shape of a heart. He's seen ants work as a team to dismember prey in minutes. "Their world is as beautiful as it is dangerous ... Every day for these tiny animals is survival."

Insects are vital to the health of the planet—and a critical base of the global food chain. They keep nutrients flowing through soil, pollinate the world's flowers and fruit crops, and spread seeds. But climate change, pesticides, and habitat loss threaten these creatures. Insect populations are in steep decline. A trained ecologist, Georgiev is acutely familiar with what's at stake for his tiny subjects. But photographing the beauty of insects thriving in their habitats, he says, "makes me dream. It makes me calm, and it gives me peace." **—NATASHA DALY**



A female meadow grasshopper, one of the most abundant of its kind in Europe, sits on a willow leaf in the Bulgarian Balkans. Most female meadow grasshoppers cannot sing, unlike males, which call to mates by rubbing their hind legs against their longer wings.

Between mushrooms, a praying mantis stretches her forelegs, which she uses to catch and hold prey. Photographer Georgi Georgiev has seen these predators hunt—even take down a lizard—but he's also noted the gentle way they clean their forelegs and antennae.

In Bulgaria's Strandzha Nature Park, Georgiev crouched in a large rainwater puddle to photograph a bog beetle, which cannot swim. From the dung beetle family, they're most abundant in deciduous forests.

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NATIONAL GEOGRAPHIC | VOL. 245 NO. 2

For the Next Pandemic

COVID-19 HAS TAKEN AND UPENDED LIVES. IT'S ALSO DELIVERED CRUCIAL LESSONS THAT CAN HELP US NAVIGATE A FUTURE OUTBREAK.

BY **PAUL A. OFFIT, M.D.**

IN *A TALE OF TWO CITIES,* Charles Dickens's 1859 novel set during the French Revolution, he wrote: "It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness." Such has been the case with the COVID-19 pandemic.

On the one hand, science saved lives. Less than a year after the virus was identified, the United States had created and tested vaccines. Then it determined how to mass-produce, mass-distribute, and mass-administer them at no cost to the public—without a preexisting infrastructure in place for mass-vaccinating adults. COVID vaccines are estimated to have saved at least 3.2 million lives in the U.S. alone. These accomplishments offer hope for how quickly we can respond to the next pandemic.

On the other hand, public health officials had inadvertently leaned into a libertarian left hook. About 30 states have now passed laws limiting health authorities from imposing protective measures

AT THE END OF 2023, NEARLY ONE-THIRD OF THE PEOPLE LIVING ON THE PLANET HAD NOT RECEIVED A SINGLE DOSE OF A COVID VACCINE. THE DEGREE TO WHICH ANY COUNTRY IS AT RISK FOR SEVERE DISEASE IS THE DEGREE TO WHICH WE'RE ALL AT RISK.

without permission from state legislators. "One day we're going to have a really bad global crisis and a pandemic far worse than COVID, and we'll look to the government to protect us, but it'll have its hands behind its back and a blindfold on," Lawrence Gostin, faculty director of Georgetown University's O'Neill Institute for National and Global Health Law, told the *Washington Post*. "We'll die with our rights on—we want liberty, but we don't want protection."

How exactly did we get here? In 2020 I was an attending physician in the Division of Infectious Diseases at Children's Hospital of Philadelphia. Then I was asked by Francis Collins, a doctor and head of the National Institutes of Health, to be part of a group that advised pharmaceutical companies on how best to construct and test COVID vaccines. I have also been a voting member on the Food and Drug Administration's Vaccine Advisory Committee since 2017.

Because of my role on these bodies, I was often asked to appear on network news programs and morning shows to explain events that were unfolding in real time. I was frequently quoted in the media, and like many in my position, I felt an enormous responsibility to get things right. As the pandemic progressed, however, we found that we weren't always right, because our decisions were often based on incomplete information. At times we would give conflicting recommendations, and as a result, many Americans lost faith in the institutions and the individuals responsible for protecting the public.

But perhaps our experiences with SARS-CoV-2—which so far has killed some seven million people worldwide—can prepare us to cope better with the next pandemic. We should heed these lessons.

VACCINATING THE WORLD IS IN EVERYONE'S SELF-INTEREST

The United States has the technological capacity and resources to vaccinate the world, and it wouldn't necessarily be an altruistic act. SARS-CoV-2 will continue to circulate and continue to create variants for decades to come. Indeed, at the end of 2023, nearly one-third of the people living on the planet had not received a single dose of a COVID vaccine. The degree to which any country is at risk for severe disease is the degree to which we're all at risk. No one is safe until everyone is safe.

THE SCIENTIFIC PROCESS TRULY IS A PROCESS

Recommendations for the treatment and prevention of COVID have evolved as we've learned more about how the virus is transmitted and who is at greatest risk. At first people were told to wash hands constantly and clean surfaces and store-bought items. Eventually it became clear that while masking was important, washing and cleaning had a lesser impact. Scientists, clinicians, and public health officials should be more careful about informing the public that all recommendations are based on what we know at the time and that things might change. Otherwise the fluidity of scientific knowledge will remain disconcerting.

GRASSROOTS CAMPAIGNS CAN BUILD REAL TRUST

Although countering misinformation at a national or statewide scale is virtually impossible, it is possible at a local level. During the pandemic, Ala Stanford showed us how. She and her Black Doctors COVID-19 Consortium sat in people's homes in North Philadelphia and provided residents with a consistent and trustworthy source of information. In a community resistant to vaccination, she and her colleagues reassured and educated more than 50,000 to vaccinate themselves and their children.

SEPARATING PARTISAN POLITICS AND SCIENCE WILL SAVE LIVES

For the first time in human history, deaths from a vaccine-preventable disease were divided along party lines. As of December 2022, 37 percent of Republicans but only 9 percent of Democrats were unvaccinated. And according to a study published in the journal *Preventive Medicine Reports,* counties in states governed by Republicans had higher rates of mortality from COVID. Because it's about resources and values, public health will always to some extent be political. But it doesn't have to be partisan—something all political parties should keep in mind.

STOPPING THE SPREAD OF MISINFORMATION IS CRUCIAL

Good luck with this one. It's like trying to clean up the flooding from Hurricane Katrina with a plastic cup. Early in the pandemic, key public health

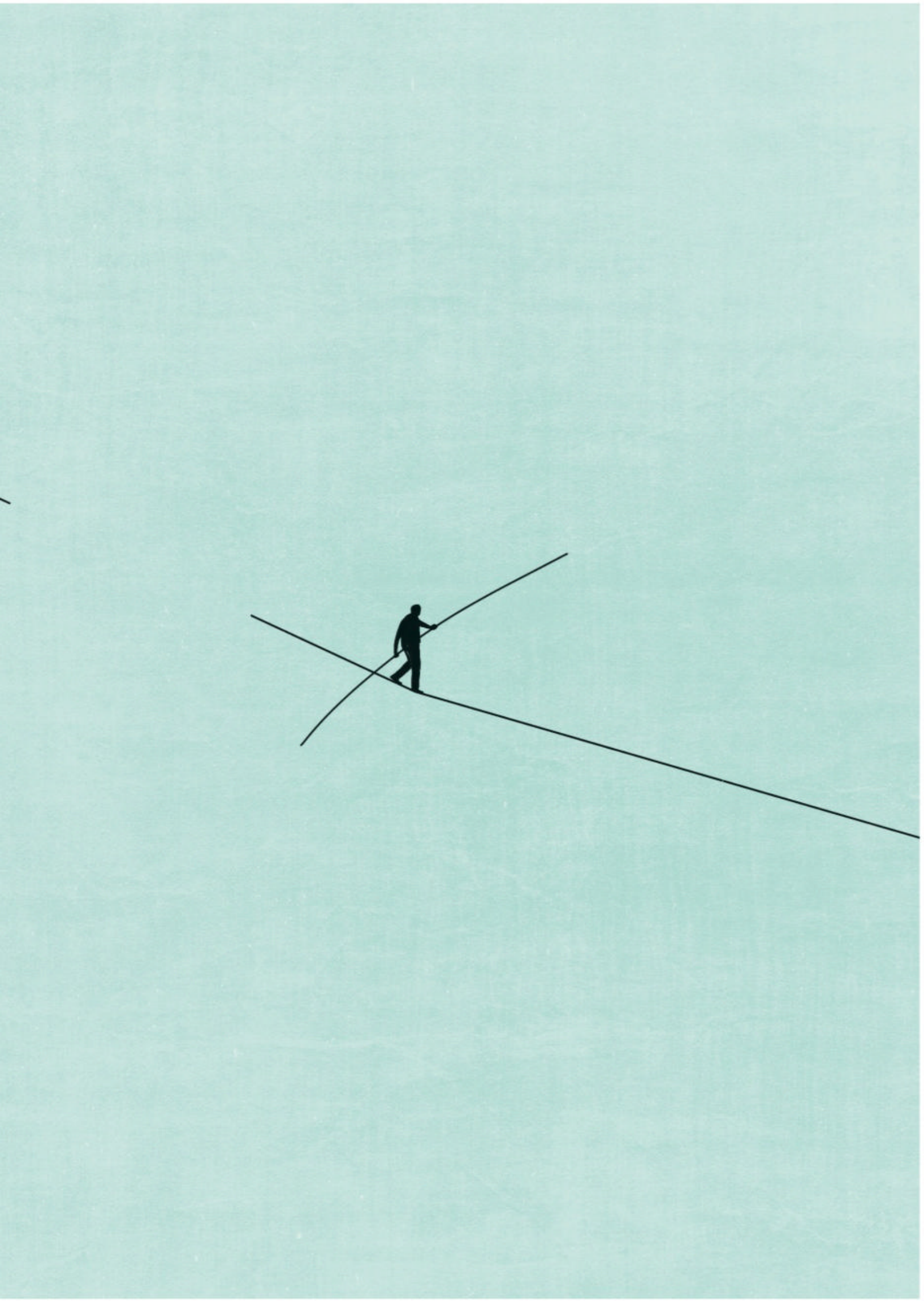


ILLUSTRATION: ANDREA UCINI

and government officials claimed that COVID was human-made—something that had never happened before in the history of the world. If you believe Carl Sagan's statement that "extraordinary claims require extraordinary evidence," then this was an extraordinary claim backed by no direct evidence—only conspiracy and innuendo.

ALWAYS PRIORITIZE THE MOST VULNERABLE

Everyone at every age is susceptible to COVID, but not everyone is equally susceptible to serious illness. Older adults suffered a death rate about a thousandfold greater than children; at times, as many as 40 percent of COVID deaths in the U.S. occurred in nursing homes. Similarly, studies of booster dosing showed that those most likely to benefit included people over 75, people with multiple health problems, those who were immunocompromised, and those who were pregnant. For as long as this virus circulates, the primary focus should be on protecting these four groups.

THE CURE SHOULDN'T BE WORSE THAN THE DISEASE

At first, the only strategy for decreasing COVID was to limit human-to-human contact. We closed businesses and shuttered schools. No one paid a bigger price for this approach than children, who suffered severely from the lack of education and socialization. The effect of these deficits will no doubt be felt for years to come. Our interest in getting children back to school should have been just as intense as our interest in getting people back to work. Indeed, at the beginning of the pandemic, the American Academy of Pediatrics strongly advocated for a return to in-person classes for students, detailing steps and considerations. This, as it turned out, was probably the best advice.

WORKING TOGETHER MAKES US STRONGER

Perhaps the brightest point of light during the pandemic was Operation Warp Speed. Only 11 months after SARS-CoV-2 was isolated, two vaccines had been tested in large clinical trials and found to be both effective and safe. Later the White House successfully partnered with pharmacies and hospitals to distribute and administer vaccines, as well as to provide test kits and antivirals. It was an amazing effort and bodes well for our ability to create and distribute vaccines against future pandemic viruses.

WE CREATED SAFE AND EFFECTIVE VACCINES IN RECORD TIME. NURSES AND DOCTORS WORKED EXTRA HOURS. IT WAS ALL HANDS ON DECK.

AMERICA HAS A LONG HISTORY of banding together. During the 1940s and 1950s, polio was a feared and devastating infection. Americans responded by sending their dimes to the National Foundation for Infantile Paralysis, otherwise known as the March of Dimes. The organization received millions of dollars, which led to a vaccine that over time eliminated the disease from most of the world. We saw polio for what it was: a shared tragedy.

On September 11, 2001, planes hijacked by Islamist terrorists crashed into the World Trade Center, the Pentagon, and a field in Pennsylvania, killing 2,977 people. Police and firefighters rushed into the collapsing buildings. We all hugged each other and cried, once again united by a shared national tragedy. To further unite us, President George W. Bush made it clear that this event had nothing to do with Muslim Americans. "The face of terror is not the true faith of Islam," he said. Again we were all in this together.

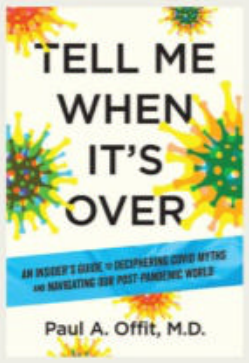
On January 20, 2020, the first case of SARS-CoV-2 was confirmed in the United States. Since then, more than a million Americans have lost their lives to this virus. Using a novel technology, we created safe and effective vaccines in record time. Nurses and doctors worked extra hours, even without proper personal protective equipment. It was all hands on deck. Again we responded to a national tragedy. We saw ourselves as part of a whole.

It's in us. We can do this. When we see ourselves as part of something greater, we tap into the better angels of our nature. ▯

Paul A. Offit is director of the Vaccine Education Center at Children's Hospital of Philadelphia, as well as the Maurice R. Hilleman Professor of Vaccinology and a professor of pediatrics at the Perelman School of Medicine at the University of Pennsylvania.

A Frontline View

This essay is adapted from Offit's book *Tell Me When It's Over: An Insider's Guide to Deciphering COVID Myths and Navigating Our Post-Pandemic World,* published by National Geographic. A definitive manual to the new normal, it's available wherever books are sold.



DISPATCHES FROM THE FRONT LINES OF SCIENCE AND INNOVATION

Bricks for birds

Swifts nest in the crevices of old buildings, but such spaces are becoming scarce. To stem a drop in the birds' population, U.K. conservationists developed "swift bricks," blocks with built-in nesting holes, and are advocating their mandatory use in new construction. –ANNIE ROTH

ASTRONOMY

LISTEN TO AN ECLIPSE

ASTRONOMERS GIVE VISUALLY IMPAIRED PEOPLE A NOVEL WAY TO EXPERIENCE THE CELESTIAL EVENT.

On April 8, 2024, the moon will slide between Earth and the sun, turning day to dusk above the ribbon of North America swept by a total solar eclipse. For people whose vision impairments prevent them from seeing it, astronomers at Harvard University have developed LightSound, a smartphone-size device that uses sonification to translate ambient brightness to sound. The piping of a flute represents bright light, a clarinet indicates when the partial eclipse begins, and soft clicking tones mark totality—that eerie darkness spanning the hundred-or-more-mile-wide band of Earth under the moon's shadow. April's path of totality reaches states from Texas to Maine. The LightSound Project will distribute some 500 devices to museums, national and state parks, and schools for the blind across the country. Harvard's Astronomy Lab manager, Allyson Bieryla, says the goal is to increase accessibility and open the field of astronomy to new perspectives. "The excitement of astronomical events can inspire the next generation of great thinkers, and we need them all." –STEPHANIE VERMILLION

ANIMAL BEHAVIOR

A whale of a trip

A humpback whale named Frodo set a species record by traveling 7,000 miles across the Pacific. Prior to that journey, he was spotted in the Bering Sea off Russia, far from the known path of humpbacks that breed in Mexico. Using Happywhale, an identification database, biologist Nicola Ransome and colleagues found that 117 other whales made similar trips, showing that migration is more complex than we thought.

–BRIANNA RANDALL

PHOTOS (FROM TOP): SIMON STIRRUP; RGB VENTURES/SUPERSTOCK/ALAMY STOCK PHOTO; ALLYSON BIERYLA; RALPH PACE, WHALE TRUST (TAKEN UNDER NMFS PERMIT 13846)

A FRIGID JOURNEY TO PROBE THE PLANET'S FUTURE

CLIMBER ALEX HONNOLD has scaled rock faces around the world, including his famous free solo of El Capitan in California's Yosemite National Park. But a more recent climb, documented in the new series *Arctic Ascent,* took him somewhere new and extremely cold. Assisting with the research of glaciologist Heïdi Sevestre, Honnold and climber Hazel Findlay (both shown above, with Honnold in red) led the first ever ascent of Greenland's 3,750-foot-tall rock wall known as Ingmikortilaq. Before reaching the summit, the team—joined by guide Adam Mike Kjeldsen and adventurer Aldo Kane—trekked for five days while dragging a sled of equipment to collect glacier melt data from hard-to-reach parts of the ice sheet.

Honnold, who usually climbs shirtless and in shorts, was pushed beyond his comfort zone. Enveloped in three jackets, three pairs of pants, two hoods, and a beanie, he could hardly see his feet. At one point, falling ice hit him in the face. But the expedition let him lend his climbing expertise to a scientific purpose: collecting valuable clues about sea-level rise and climate change. "If you're going somewhere and you have the opportunity to help," he says, "you really should." **—DANIEL STONE**

PHOTO: PABLO DURANA, NATIONAL GEOGRAPHIC. NGM MAPS

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ARMOR FIT FOR ANIMALS

PHOTOGRAPH BY **CHRISTIE HEMM KLOK**

1. Dividers
When measuring on curved surfaces, like a helmet visor, they ensure symmetry.

2. Dapping tools
De Boer has multiple sizes for sculpting metal domes, which can be the first step in a new armor element.

3. Jeweler's pitch
This black tarlike adhesive holds sheet metal—such as a brass piece—in place as it's being decorated.

4. Jeweler's saw
The switchable blades allow de Boer to cut forms from various materials with ultrafine precision.

CAT AND MOUSE. Eternal adversaries, ever alert to each other's maneuvers, playing a deadly game of, well, you know. But what if these two combatants were outfitted like history's warring humans, dressed as, say, Japanese samurai or Tudor-era knights? Canadian artist Jeff de Boer explores this fanciful conceit by making museum-quality armor for cats and mice—not for the animals to wear but for people to enjoy. Since the 1980s, he's created about 800 suits, transforming ordinary metal into masterpieces that are "small but mighty." –HICKS WOGAN

5. Chasing hammer
With this tool, he makes indentations in a metal surface to add detail, a process called chasing.

6. Forming stake
This custom-made device helps de Boer mold durable metals—often brass, nickel, silver, or steel.

7. Hammers and files
The former are used for shaping or riveting, and the latter for milling, rounding, or trimming.

8. Torch
Heat makes the metal more malleable. To watch de Boer at work, visit *natgeo.com/armor*.

INNOVATOR

FERNANDO TRUJILLO

Fernando Trujillo holds the snout of an Amazon river dolphin while his team measures and examines the animal before returning it to the water. The Colombian marine biologist has spent more than 30 years protecting river dolphins.

He advocates for the Amazon's 'pink ambassadors.'

The alarms last September from Brazil's Lago de Tefé first reached Fernando Trujillo by phone—his colleagues, fellow scientists, calling him in a panic. The brutal 2023 summer had been heating the Amazonia lake to temperatures far beyond anything previously recorded, and as they had feared, something was now happening to the pink river dolphins. "Three dead dolphins," Trujillo remembers. "Then five dead dolphins. Then 70 dead, in one day."

For Trujillo, a Colombian marine biologist and National Geographic Explorer who's become a global advocate for river dolphins, the Tefé disaster must be understood as both a tragedy and a much needed lesson in the vulnerability of these freshwater ambassadors. Over just a few days, 157 dolphins—10 percent of the lake's population—died in that overheated water, which pushed above 102°F. The exact cause was still under investigation two months later, but heat stress seemed the likeliest explanation. Trujillo says the sudden attention to the mass deaths may help people grasp other threats—habitat loss, poisoned waters, overfishing, outright slaughter—that imperil river dolphins in all 14 countries where they're found.

He's been at the work ever since he was a university student and the venerated oceanographer Jacques Cousteau visited his class. ("I asked him what would be important to study. And he said: *'Dauphins.'* Dolphins. It was kind of like an order.") Part of the National Geographic and Rolex Perpetual Planet Amazon Expedition, a series of scientific research projects spanning the Amazon River Basin, Trujillo is also helping coordinate international conservation commitments like the Global Declaration for River Dolphins. "And the main point is, it's not just about the dolphins," he says. "It's about the rivers, and the 1.5 billion people living there. The dolphins, for me, are connecting the general public to all the problems in the region. And the general public is listening." —CYNTHIA GORNEY

This article was supported by Rolex, which is partnering with the National Geographic Society on science-based expeditions to explore, study, and document change in the planet's unique regions.

PHOTO: THOMAS PESCHAK

NATIONAL GEOGRAPHIC

Real a bug's life

narrated by awkwafina

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From Bridge to Buzz

AUSTRALIA TURNED A PIECE OF INFRASTRUCTURE INTO AN UNLIKELY TOURIST ATTRACTION—AND INSPIRED THE RISE OF URBAN ADVENTURES.

BY **LARRY BLEIBERG**

I'M STANDING on a steel walkway 440 feet above Sydney Harbour when a voice crackles over my headset. My guide tells me to look right and take in one of the world's most stunning skylines.

The view: the familiar clamshell roof of the Sydney Opera House and the ferries crisscrossing the sparkling water. Below me, cars and trains rumble across the world's tallest steel-arch span. But up here, as twilight descends, with my head nearly in the clouds, it feels as if I'm floating over a toy city.

I now see why scaling the Sydney Harbour Bridge ranks as one of Australia's most popular activities, attracting more than four million climbers since the first customer stepped onto its steel beams 25 years ago. The climb has helped make the bridge an instantly recognizable landmark and a lure for anyone visiting the continent. It also helped change tourism around the world.

The experience appealed to a new generation of thrill-seeking travelers. "People wanted more than just the usual, than just seeing the sights. They wanted to do things which at least on the surface look a little scary," says David Beirman, an adjunct fellow at the University of Technology Sydney, where he researches tourism and destination marketing. "The bridge climb ticked a lot of boxes."

It also helped pave the way for a surge of new urban adventures, such as traversing glass-floored observation decks and scaling skyscrapers.

As thrilling as it is, the Sydney bridge climb is surprisingly easy, attracting customers ages eight to 100, who pay more than $200 (U.S.) for the privilege.

Climbers stand at the apex of the Sydney Harbour Bridge. Its arch mirrors the distinctive sails of the Sydney Opera House.

The summit has been the site of countless marriage proposals and more than 30 weddings. Every five minutes during peak periods, a guide leads small groups onto the bridge superstructure. They then ascend ladders and follow catwalks built for maintenance workers.

Climbers strap on harnesses and remain clipped to safety cables during the entire journey. They wear identical blue jumpsuits to blend in with the bridge and not distract drivers. All customers must also take a Breathalyzer test and pass through metal detectors. "You can't have any loose clothing, cameras, sunglasses. Imagine a camera falling from high and smashing a windscreen," says Barry Newling, an official with the government agency that owns and operates the span. "You'd have a catastrophe." ▯

Reaching New Heights

In Kobe, Japan, visitors follow a catwalk under **Akashi Kaikyo Bridge,** one of the world's longest suspension spans. After climbing New Zealand's **Auckland Harbour Bridge,** thrill seekers can bungee jump from it. Guided tours of the **New River Gorge Bridge** in West Virginia cross a walkway a dizzying 876 feet above the water.

PHOTO: DESIGN PICS INC./ALAMY STOCK PHOTO

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EXPEDITIONS

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FEATURES

64

AFTER A LONG WINTER DORMANCY WHEN THEIR ENTIRE BODIES FREEZE, WOOD FROGS THAW OUT AND BEGIN THEIR MATING RITUAL IN SPRING POOLS.

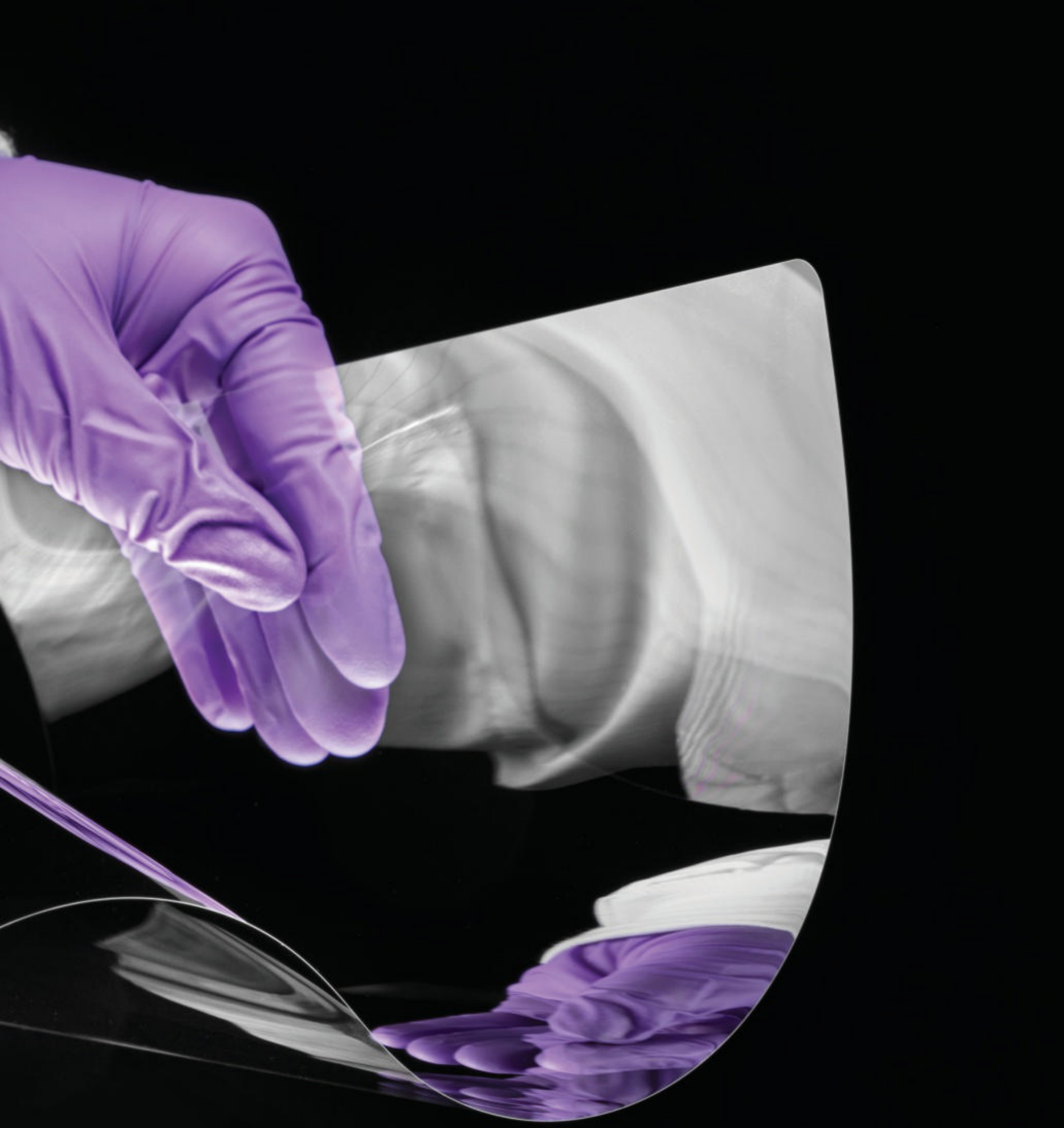
PHOTO: TRISTAN SPINSKI

Technicians in upstate New York pour a batch of molten glass at Corning's "test kitchen." Here, the company tries new recipes to enhance features such as strength, color, and optical clarity.


AREA
THE GLASS AGE

WHERE

A paper-thin sheet demonstrates the flexibility of Corning's bendable glass: an innovation that allows for foldable phone screens and curved automotive displays.



GLASS BENDS

AND GLASS

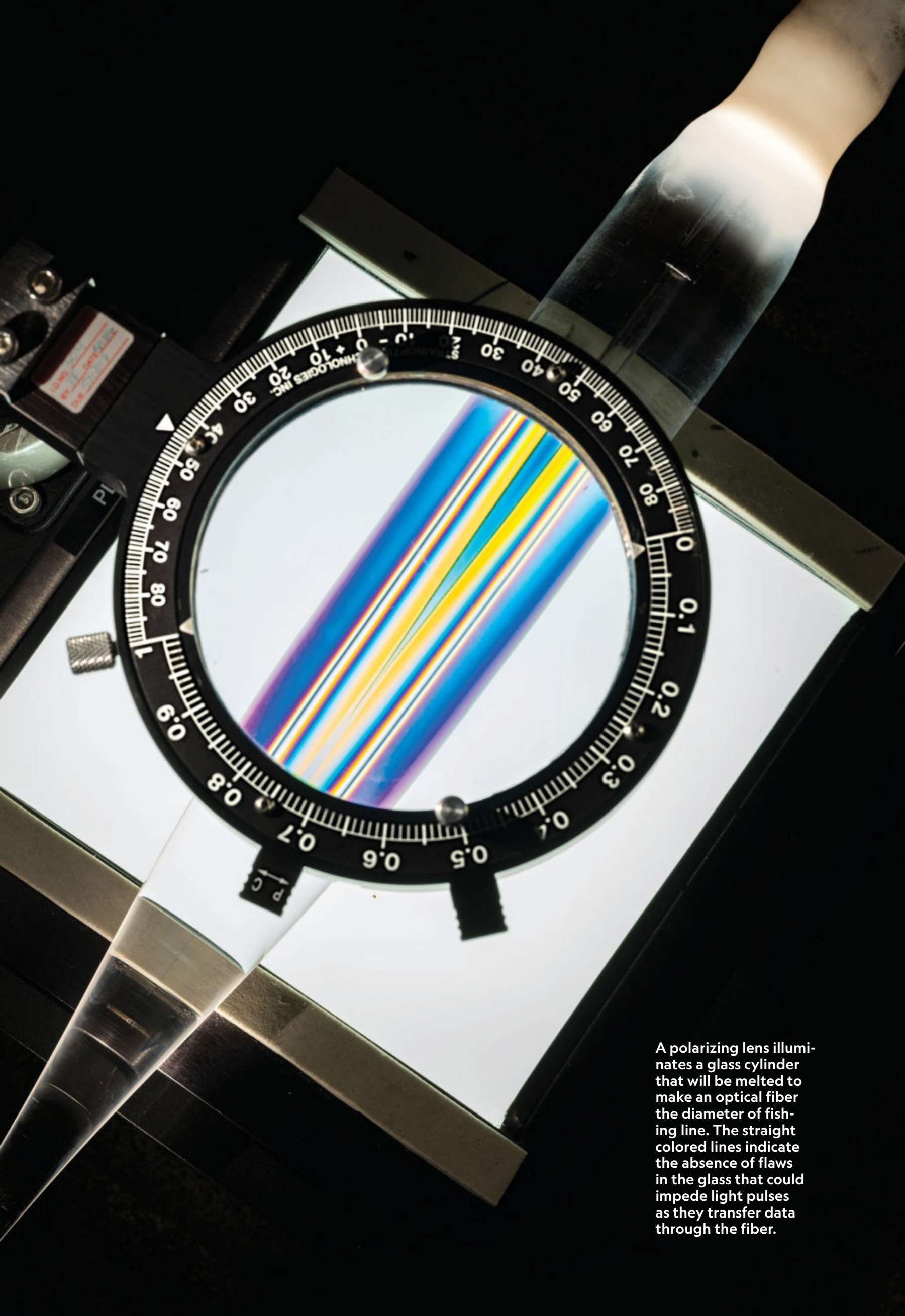
A high-speed strobe captures the rebound of a thimble-size piece of glass grown in tandem with polymers. Developed at Imperial College London, “bouncy bioglass” is being tested to help regenerate cartilage.

BOUNCES

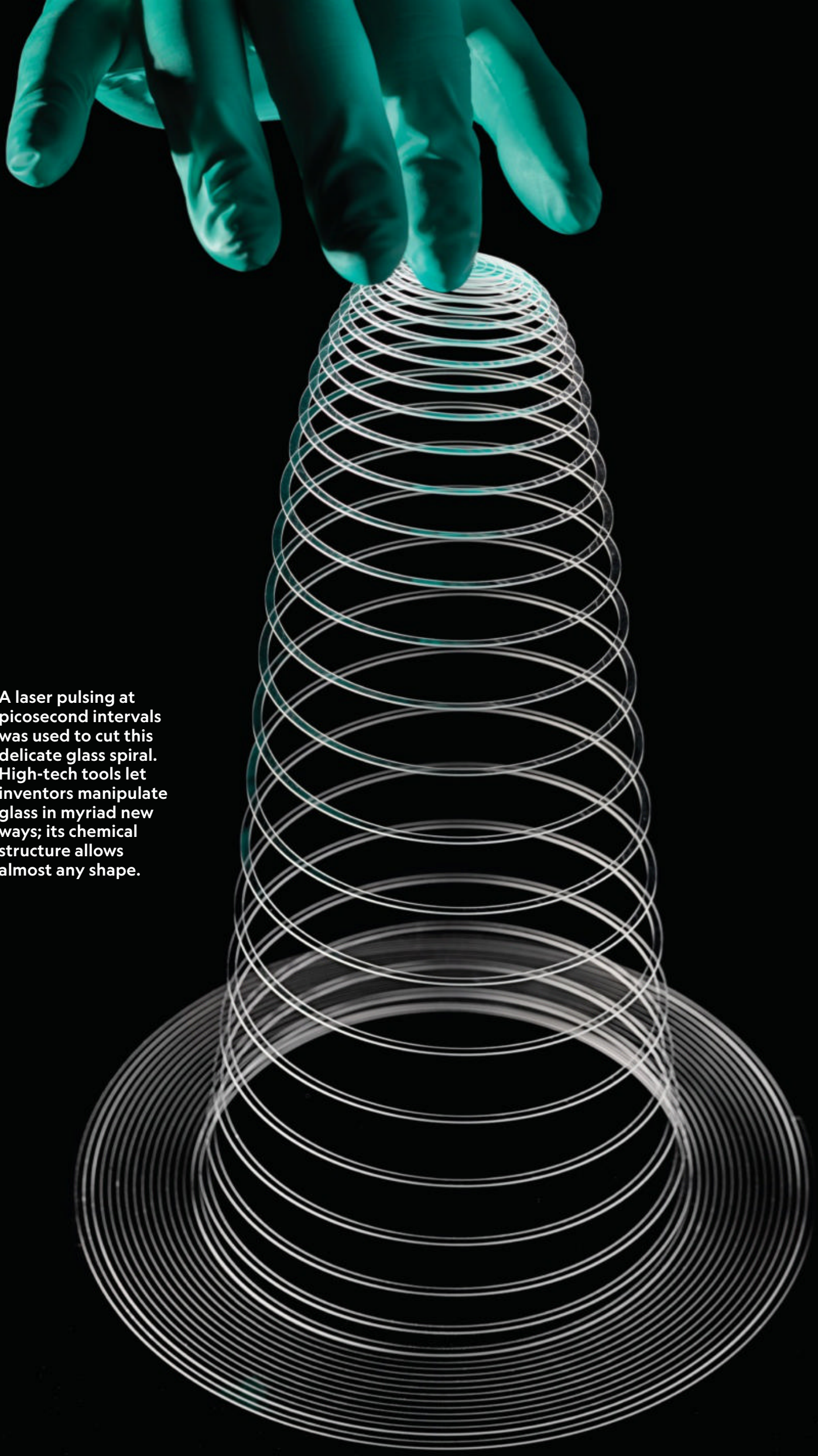
THE MODERN WORLD RUNS ON GLASS, A MATERIAL THAT HAS BECOME ESSENTIAL TO HUMANITY.

BY **JAY BENNETT**

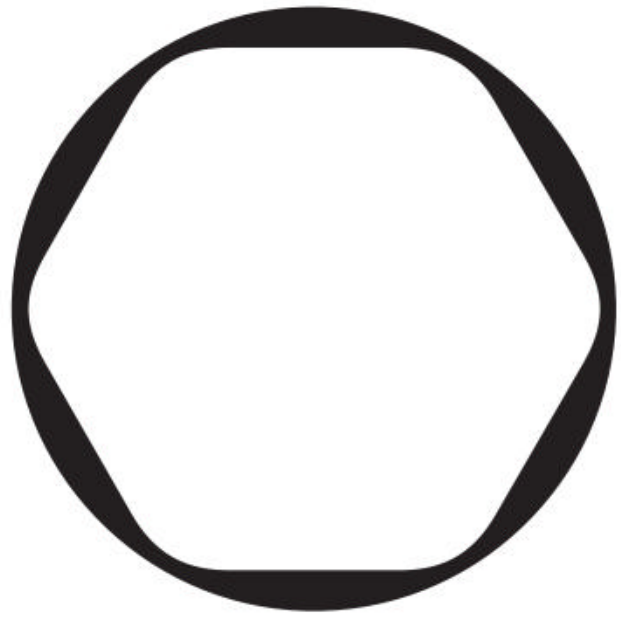
PHOTOGRAPHS BY
CHRISTOPHER PAYNE



A polarizing lens illuminates a glass cylinder that will be melted to make an optical fiber the diameter of fishing line. The straight colored lines indicate the absence of flaws in the glass that could impede light pulses as they transfer data through the fiber.



A laser pulsing at picosecond intervals was used to cut this delicate glass spiral. High-tech tools let inventors manipulate glass in myriad new ways; its chemical structure allows almost any shape.



ON A BRISK MARCH AFTERNOON, Kazuhiko Akiba and a colleague stood in the courtyard of the Chiba Kogaku glass factory in Japan, ready to unveil their latest creation. A forklift wheeled out a large clay pot about the size of a hot tub and set it down before them. Dressed in the company's sky blue uniforms, the men put on safety glasses and gloves. Then each grabbed a sledgehammer, hefted it overhead, and slammed it against the outer edges of the pot. Their blows landed with solid thwacks, chipping away heavy ceramic to reveal the prized contents beneath: a hard, luminous substance that caught the afternoon sun. It glowed in pale cerulean hues, like Arctic ice.

Akiba, the factory director, stepped back in admiration. *"Kirei,"* he said. Beautiful. This was the latest batch of what's known as E6, some of the world's purest optical glass.

Located east of Tokyo and surrounded by peanut farms, Chiba Kogaku has been making glass in handmade clay pots for more than 50 years. The technique dates to the early 1800s, when Swiss lensmaker Pierre-Louis Guinand pioneered the method of using ceramic stirrers to mix molten glass. That process yielded a product devoid of bubbles and contaminants and ideal for optics. In 1965 a Japanese firm, Ohara Glass, refined the process with its own admixture to develop E6, a so-called low-expansion glass that's now made for Ohara only at Chiba Kogaku.

A single pot, holding about 200 gallons, takes roughly four months to create. First, the clay vessel must be hand-sculpted. Then workers pour in a mix of silica, boron oxide, aluminum oxide, and other materials and heat the pot to 2700 degrees Fahrenheit. As it melts, the molten glass must be stirred periodically for more than two days before the pot is placed in a temperature-controlled chamber to cool for two weeks.

Breaking the clay pot removes the outermost layer of glass, leaving behind a pure substance that can be remelted and formed into precise shapes that remain constant even in extreme temperatures—hence, the "low expansion" part of its name. This stability is crucial when you're trying to build glass mirrors for large telescopes.

The market for such wildly expensive instruments, the kind that let astronomers peer into the deep recesses of space, is limited. So limited that all the E6 produced in the past 42 years has been delivered to a single buyer. A huge amount—134 tons—is for a project that, if successful, will change the way we think about the universe.

E6 is just one example of how glass is being reinvented to explore a range of frontiers. In fact, glass has seen more technological and industrial developments in the past half century than in the previous millennium, prompting the UN in 2022 to recognize glass as the 100 percent recyclable

A Corning employee marks sections that will be cut from a “boule” of fused silica glass. The material’s purity and strength make it ideal for advanced lenses, beam splitters, and other optical devices, as well as windows for spacecraft and submarines.


MAY
94109

A vial that will hold vaccines is fired using a shatter-resistant glass specially formulated to guard against interfering with chemicals in the drug. As production of COVID vaccines ramped up, the manufacture of reliable vials became a global priority for glassmakers.

building block most likely to help coun
sustainable-development goals by 20

Simply put, we've entered a new gla
in which scientists will use this ancien
to radically improve our lives.

At the factory, Akiba warns me no
the newly exposed glass because its
covered with tiny shards. As the sur
massive chunk continues to change h
mering with hints of topaz, then aq
and silver. Transfixed, I watch the co
form, the otherworldly material spa
though golden stars were suspended

THERE'S A POPULAR INTERN
showing the moment toddlers
with their first pair of eyeglass
video, a child goes from bawli
fused to looking stunned and
as he or she for the first time c
see his or her parents. That's l
year-old me felt as I walked
Costco wearing my first pair of glasses
in amazement at the sharply defined s
all thanks to a technology developed
700 years ago and used by billions of pe

Getting eyeglasses has become su
dane part of modern life that we've prac
gotten the impact the invention of opt
has had on civilization. But that's true
the ways that glass has profoundly ch
human experience. Try imagining lif
bottles and baking dishes, mirrors and
light bulbs and televisions. If you're re
story on your mobile phone, you tapp
touch screen and these words popped
via data that traveled on glass fiber-op

Humans have been progressively we
material ever deeper into their lives
discovered how to produce it about 4
ago. While it's unknown exactly wher
glass was created, some of the oldest g
and other trinkets have turned up in M
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have been the accidental by-product
or metal production. Whatever the ca
quickly figured out how to manipulat
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Whether ancient or modern, nearly all glass contains the same basic formula: a mixture of silica (the primary ingredient), soda ash (to lower the melting point), and limestone (to stabilize it). But part of what makes glass special is a sort of accident of nature—the result of a process interrupted. When the main ingredients are heated to about 1800 degrees Fahrenheit and then cooled, the atoms in the mixture naturally want to form a structure like the crystalline matrix in a sheet of ice or a diamond. Instead, the atoms become trapped in a random configuration yielding something between a solid and a liquid, which can be reshaped before it cools and hardens. The result is called an amorphous solid.

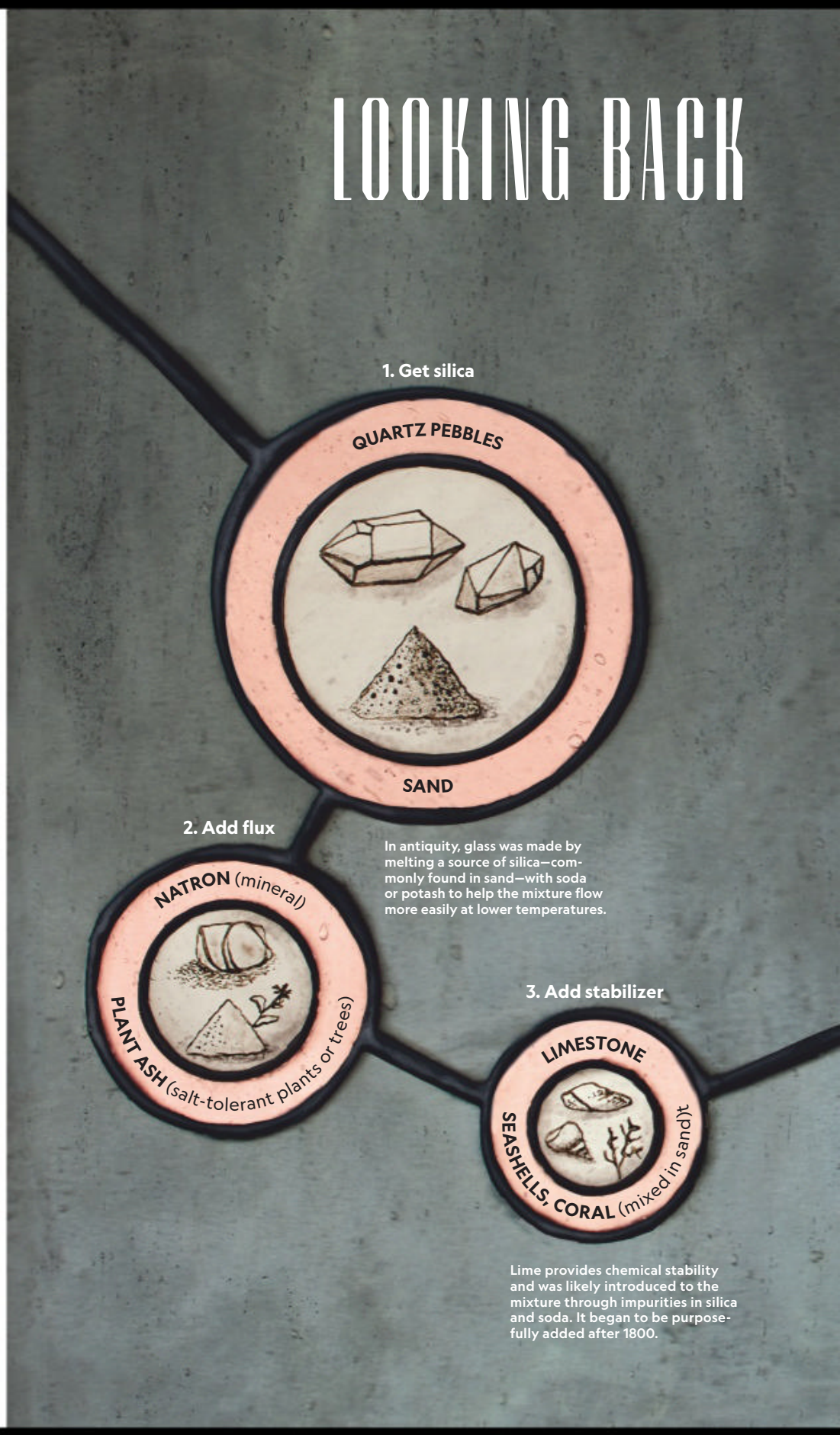
This disordered molecular structure is what gives glass its superpower: a chameleonlike adaptability. Since there's no need for its atoms to lock into a specific pattern, at elevated temperatures its structure can incorporate a wide range of chemical compounds. Such additions can provide color, flexibility, greater heat resistance, and increased strength, among other desired traits.

"The compositions of glass are infinite, and you can continuously change their properties," says Alicia Durán, a glass professor at the Spanish Research Council and past president of the International Commission on Glass, which has worked with the UN to champion the new glass age (a term Durán often uses).

But she loves glass for another reason: "The main quality of glass is that it can be produced, reproduced, born and reborn—really in the same or other applications—forever. And so this is the basis for sustainability," she says.

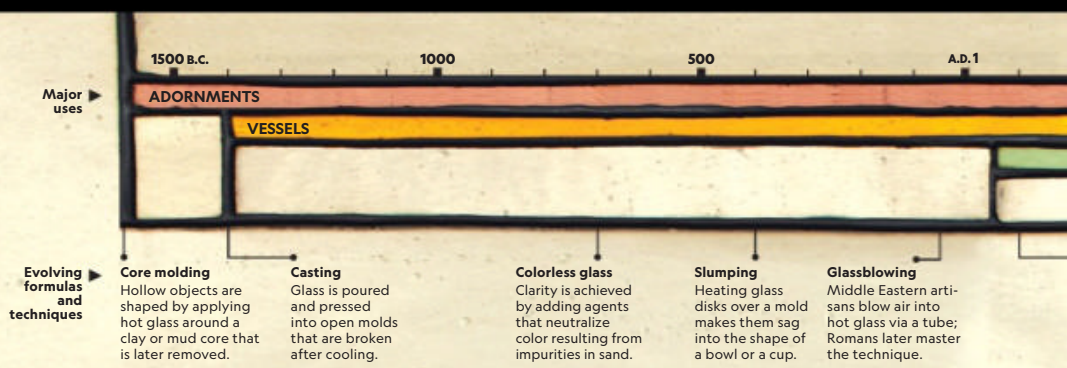
For scientists, that creates an opportunity for endless experimentation, and the centuries have

GETTING EYEGLASSES HAS BECOME SUCH A MUNDANE PART OF MODERN LIFE THAT WE'VE FORGOTTEN THE IMPACT THE INVENTION OF OPTICAL LENSES HAD ON CIVILIZATION.



REVEALING HISTORY

Archaeological evidence suggests that organized glass production began in the Middle East and Mediterranean region over 35 centuries ago as an alternative to ceramics. From the earliest iterations of glass as small, opaque, colorful beads and other adornments to today's cell phone screens, fiber-optic cables, and next-generation telescopes, glass continues to advance.



1600 B.C.-TODAY

ADORNMENTS

Pendants, beads, and amulets are some of the first objects fashioned from glass—almost exclusively for the wealthy. Made throughout history, they're a popular item found along trading routes worldwide.

Noteworthy objects in the history of glass

Syrian amulets
1500 B.C.
Early evidence of object type

Phoenician pendants
650 B.C.
Possibly for warding off evil forces

Chinese eye beads
300 B.C.
Found in burial sites, thought to offer protection

Indo-Pacific beads
200 B.C.
Simple, round, and the most widely traded of all ancient beads

Japanese amulets
A.D. 700
Believed to represent the human spirit and offer protection

1400 B.C.-TODAY

VESSELS

Small vials had been made for centuries, but the advent of glass-blowing around 50 B.C. introduces abundant, cheap, thin-walled vessels in many shapes and sizes. Glass becomes common in households.

Egyptian perfume bottles
1400 B.C.
Thin rods of colored glass decorate core-molded pieces

Roman ribbed bowls
75 B.C.
Ubiquitous, inexpensive, and made in various colors

Sassanian cups
A.D. 200
Ancient Persians imitate Roman-style faceted decorations

Byzantine jugs
A.D. 500
Keepsakes for pilgrims to Jerusalem, filled with oil, water, or soil

Northern and central European forest glass
A.D. 1000
Greenish vessels made from tree ashes (potash)

A.D. 50-TODAY

WINDOWS AND LAMPS

Windows might first have been used in Roman bathhouses, to let in light and trap heat. Transparent and strong, glass becomes standard for protecting candle lamps in domestic and religious spaces.

Roman windowpanes
A.D. 50
Small, irregular, thick, and not fully transparent

Byzantine hanging lamps
A.D. 500
Vessels lit by burning fiber wicks in oil

Gothic cathedral windows
A.D. 1065
Intricate stained glass patterns with inscriptions and religious scenes

English home windows
A.D. 1500
Wooden frames hold small, irregular panes

A.D. 1200-TODAY

MIRRORS AND INSTRUMENTS

New glass formulas provide the chemical stability needed for use in scientific experiments, transforming medicine, chemistry, and optics. Venetian glass mirrors gain popularity, replacing metal ones.

Convex lens (corrects farsightedness)
A.D. 1286

Concave lens (corrects nearsightedness)
A.D. 1450

Eyeglasses
For those with impaired vision, reading and working years nearly double

Tin-mercury mirrors
A.D. 1507
Developed in Venice, production using toxic mercury is hazardous

French mirror casting
A.D. 1680s
Large mirrors such as those at Versailles are made by rolling molten glass flat onto a metal plate

Telescopes (A.D. 1608) and microscopes (A.D. 1665)
Distant stars and planets, as well as the tiniest plant cells, can be seen for the first time

THIS GRAPHIC WAS CREATED BY CUTTING, PAINTING, AND ASSEMBLING 112 PIECES OF STAINED GLASS IN THE CLASSIC METHOD USED IN CHURCH WINDOWS.
PHOTOGRAPHY: REBECCA HALE AND MARK THIESSEN, NGM STAFF

500 1000 1500 1900

WINDOWS AND LAMPS

MIRRORS AND INSTRUMENTS

Mold blowing
Glass is blown into molds that can be reused indefinitely—marking the start of mass production.

Stained glass
Artists use glass as a canvas, painting with metal oxides to depict imagery and tell stories.

Venetian glass
Italians create a beautiful glass with fewer bubbles and impurities.

Bohemian glass
The first glass to purposefully include a stabilizer is artfully cut and engraved.

Gold ruby glass
A German alchemist solves how to widely produce red glass: Add gold.

Lead glass
The English refine this sturdy and reflective formula.

Pressed glass
Americans take the first step toward mechanized production.

Venetian chevron beads
A.D. 1500
Hollow tubes of hot, multilayered glass that are stretched, cut, and cooled

West African beads
A.D. 1800
Usually shaped like an eye or a cross; revered as a source of great power

Machine-cut crystal
A.D. 1891
The introduction of electric tools allows for fast and precise shaping

Venetian *cristallo* glass
A.D. 1450
Elaborate, clear decanters showcase local wines

English wine bottles
A.D. 1650
Practical, robust, and good for storage and transportation

Chinese snuff bottles
A.D. 1700
Indispensable personal accessories for inhaling tobacco

American pressed glass
A.D. 1825
Decorative, affordable, and mass-produced

Whale oil lamps
A.D. 1780
Common in homes, the long-lasting oil burns brightly

Gas streetlamps
A.D. 1807
Public safety prompts the adoption of these efficient lamps

Incandescent light bulbs
A.D. 1879
The glass vacuum bulb introduces a new era of lighting

Tiffany Studios lamps
A.D. 1897
Pieces of opalescent glass in elaborate designs

Barometers (A.D. 1643) and thermometers (A.D. 1654)
Glass vacuum tubes hold a liquid that reacts to changes in barometric pressure or temperature

Silvered-glass mirrors
A.D. 1835
Thin metal coating paves the way to mass production of mirrors

Photo cameras
A.D. 1839
Light is exposed to a glass plate coated with light-sensitive chemicals

Glass production has seen some of its greatest advances over the past century. Transformative inventions include the bottlemaking machine, the ribbon machine—capable of producing 1,600 light bulbs a minute—and the float process, which yields large, continuous sheets of flat glass.

20TH CENTURY AND BEYOND

Televisions, 1932
Early TV technology includes electron guns shooting toward phosphor-coated glass screens; color TV arrives in 1954

Safety glass, 1911
Laminated and tempered glass, strong with predictable shattering patterns, transforms transportation and construction

Pyrex, 1915
A shatter-resistant glass with boron, invented in Germany in 1887, is adapted in the U.S. under the Pyrex brand; used in kitchens, labs, and telescopes

Glass ceramics, 1952
An engineer accidentally overheats glass and discovers an ultrastrong, heat-defying material later used in cookware, dentistry, and optics

Low-loss optical fiber, 1965
Light-transmitting, flexible glass first used in long-distance telephone wires spreads to cable TV and the internet

Space telescope glass, 1968
High g-force launches and extreme temperatures in orbit demand great tolerance for heat and cold and ultradurability

Pharmaceutical glass, 2017
Resistant to ultralow temperature, contamination, and breakage; used in vaccine distribution, including COVID-19's

Mobile-device glass, 2008
Thin and scratch resistant, the sturdy touch screen is introduced with the first-generation iPhone

SOURCES: CORNING MUSEUM OF GLASS; SETH RASMUSSEN, NORTH DAKOTA STATE UNIVERSITY

AT GLASS

Historians remain unsure about the exact origins of human-made glass, but it's clear that by around 4,500 years ago, people were melting basic ingredients to create the lustrous material. Ever since, cultures have developed new types, improved manufacturing methods, and found innovative uses, making glass a central part of daily life.

BY **DIANA MARQUES**

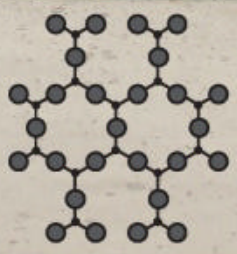
Today windows and bottles still have a silica-soda-lime composition. But tens of thousands of new formulas have led to myriad types of glass with varying properties.

Much early glass was pale blue-green because of iron impurities. Over time, metals were added to create vibrant colors that illuminated the beauty of glass objects.

A SHAPE-SHIFTING SOLID

ROCK CRYSTAL
(clear quartz)

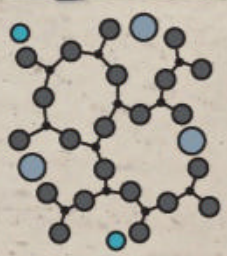
Rock crystal resembles glass and is also mostly made of silica, but it's a solid, with atoms ordered in a rigid lattice.



- Silicon
- Oxygen

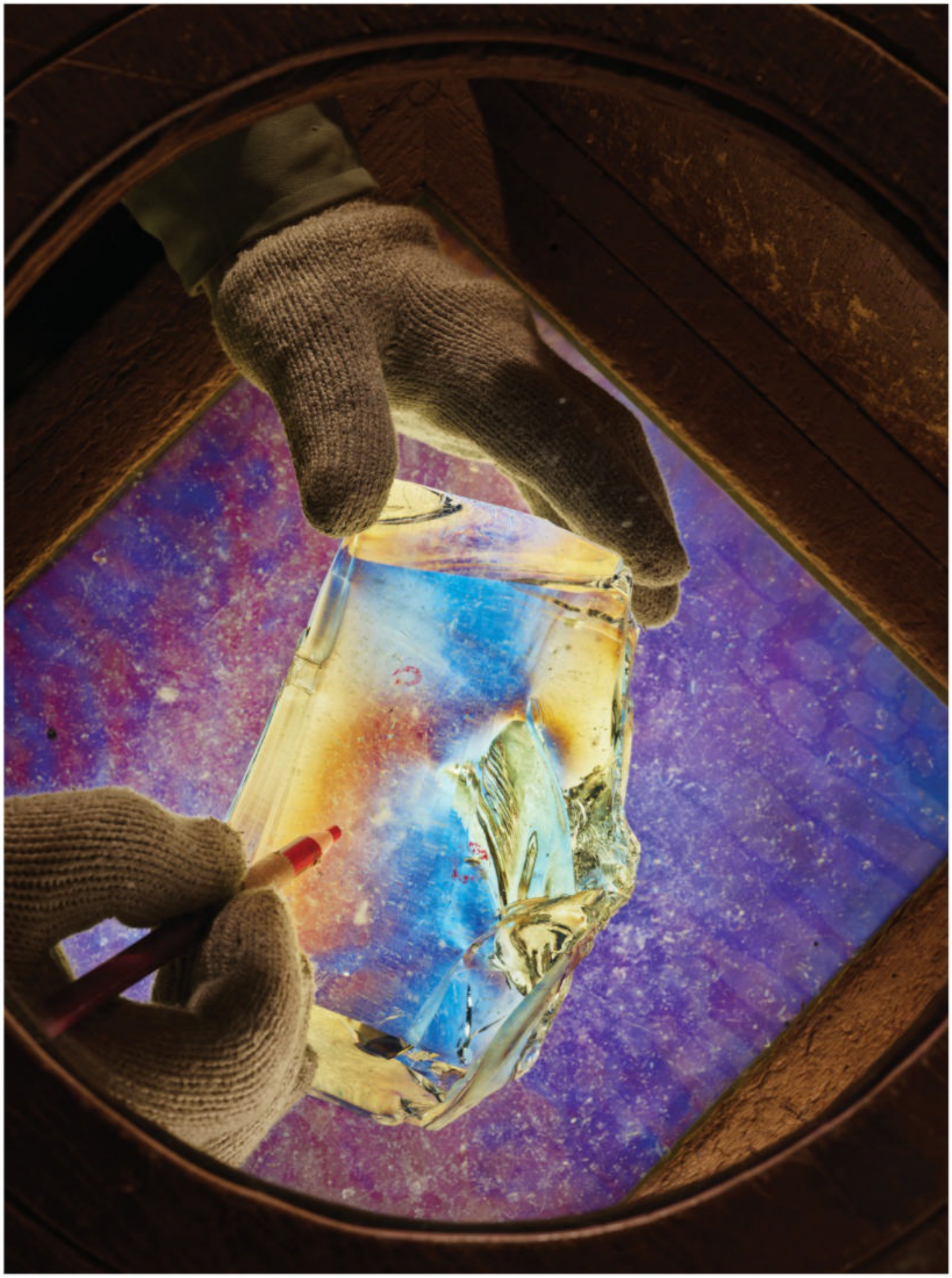
GLASS
(typical window glass)

Glass is an amorphous solid, which means it has disordered molecules like a liquid but is too viscous to flow at room temperature.



- Sodium (from flux)
- Calcium (from stabilizer)

Workers at Japan's Chiba Kogaku glass factory break a clay pot to extract a 1,500-pound chunk of a highly pure glass called E6. Produced using a century-old process, the glass will eventually be shipped to scientists at the University of Arizona in Tucson.



After the E6 glass is removed from the clay pot, a worker scores the surface with a tungsten-tipped hammer and then heats the crack with a blowtorch (left), causing the crack to widen evenly and the slab to split. The glass is then cut into small blocks, and a polarizing lens is used to inspect each one for imperfections (above). The blocks that pass inspection are then shipped to the Richard F. Caris Mirror Lab at the University of Arizona, where they'll be remelted and cast as mirrors for the Giant Magellan Telescope.

Workers at the University of Arizona hand-load 19 tons of E6 glass into a rotating furnace that will cast the final mirror for the Giant Magellan Telescope. The glass is melted over a honeycombed mold, which will give the 27.5-foot-wide mirror a stiff, lightweight structure. Once cast, the mirror will be slowly cooled for three months, after which it will undergo an extensive grinding and polishing process that could last a year or more.

shown how one advancement can continue to inspire another. Case in point: On a recent day, I visited the "test kitchen" at the Engineering and Materials Processing lab at Corning, the multinational glass and ceramics company located in upstate New York. There, technicians clad in heavily insulated, heat-reflecting suits and face shields used steel pokers and tongs to remove a white-hot cup of molten glass from an industrial furnace, carefully pouring one of the thousands of new formulas they regularly experiment with here. (Claiming trade secrets, they wouldn't tell me anything about the one I saw them working on.)

Famously, Corning teamed with Thomas Edison to improve his light bulb in 1879. Since then, the company has debuted a parade of glass firsts, from durable Pyrex labware (used to produce penicillin and distribute the first polio vaccines) to early fiber-optic lines (the backbone of the information superhighway) and ultradurable Gorilla Glass (which—usually—keeps your phone screen from shattering).

While much of what's in development at Corning remains secret, plenty of researchers are openly sharing their next targets. Take bioactive glass: In 1969 a University of Florida professor discovered that if you swap out some silica for calcium, you're able to create fine glass pellets or powders that bond with shattered bones, speeding up healing.

That discovery has led to bioglass being

ASTRONOMERS HAVE LONG BEEN CONFOUNDED BY THE CHALLENGES OF CASTING LARGE MIRRORS; THE BIGGER THEY GOT, THE HEAVIER AND MORE UNWIELDY THEY BECAME.

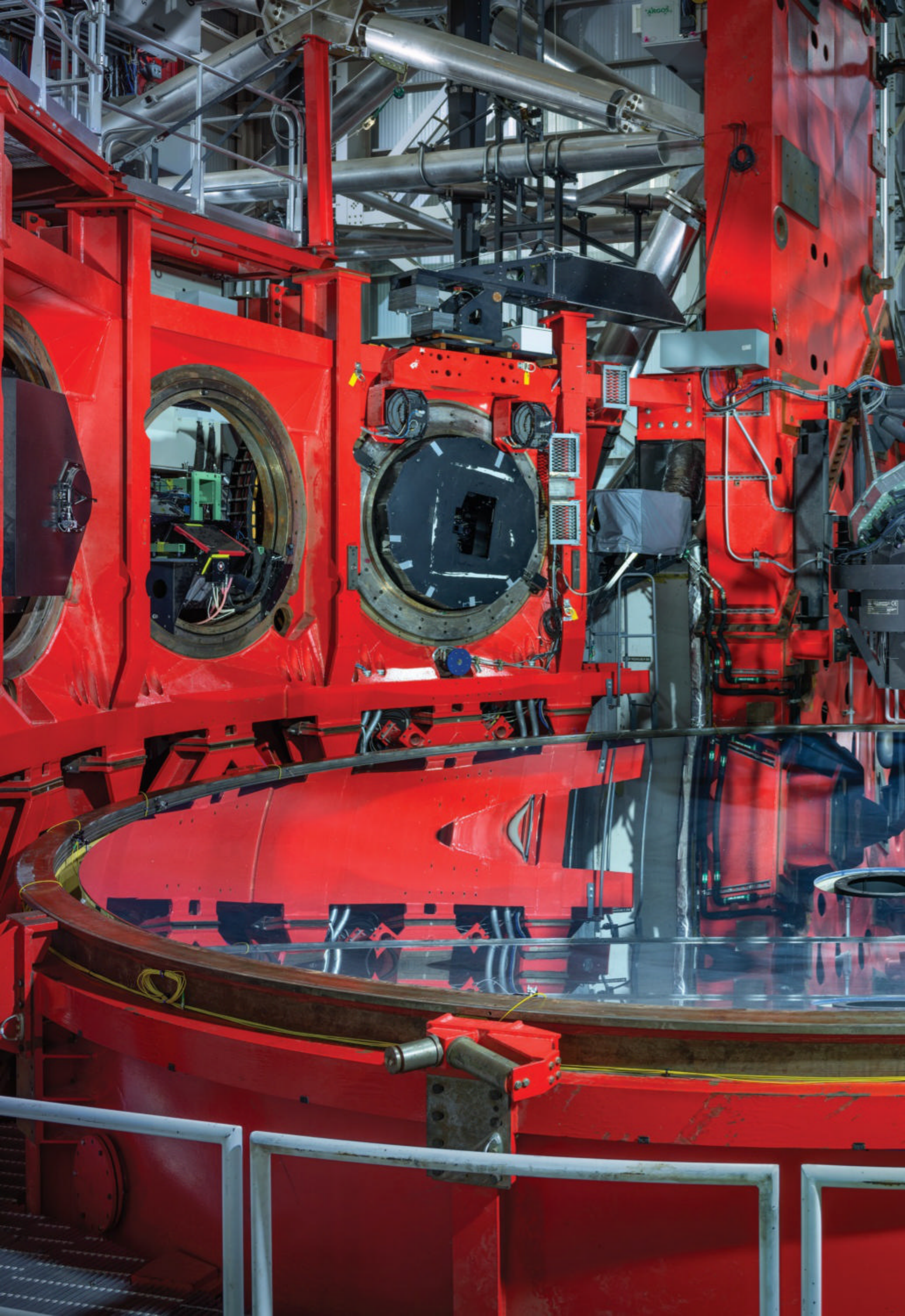
reformulated as a potential treatment for infections in bones and soft tissue wounds, says Julian Jones, a materials scientist at Imperial College London who has been studying bioglass for 25 years. If effective, the idea could solve one of the most vexing issues facing medicine, as growing numbers of pathogens evolve to become resistant to antibiotics. Jones pioneered a "bouncy bioglass," an experimental 3D-printed, rubbery, glass polymer, designed to regrow cartilage. "For older patients with arthritis," he says, "this is kind of the holy grail of cartilage regeneration."

For Himanshu Jain, who directs the Institute for Functional Materials and Devices at Lehigh University, glass will play a crucial role in renewable energy. It's already a key material in solar panels and fiberglass blades for wind turbines. Why not, Jain asks, create windows that convert solar energy into electricity? He also foresees other glass breakthroughs: glass fertilizer pellets that release nutrients and glass computer chips able to process information via light instead of electrical signals.

One of the more controversial uses for glass technology comes from the Pacific Northwest National Laboratory in Washington State, where scientists say they've improved upon a decades-old method to immobilize radioactive material. The team's goal is to devise a way to contain the 56 million gallons of stored nuclear waste that still exists at the Hanford Site, a plant that processed plutonium for the Manhattan Project and during the Cold War. "Our waste has virtually the whole periodic table of elements in it, and that has atoms of multiple different sizes that like to bond with different angles," says John Vienna, the scientist who leads the research.

To solve this problem, the team came up with many kinds of glass to incorporate the different types of radioactive pollutants. The vitrified waste will outlast the radioactive half-life of most of the toxic material—although much debate continues over where to safely store it. After Vienna and I spoke, the team overseeing the vitrification process agreed to mail me a small chunk of test glass—made from nonradioactive material—to show me what the storable waste would look like.

When the package arrived, I pulled out a smoky gray lump, about the size of a deck of cards. It wasn't beautiful like the chunk of E6, but the thought it could help resolve a long-standing environmental disaster gave it a different allure.



Technicians clean an E6 glass mirror on the Large Binocular Telescope located on Arizona's Mount Graham. The mirror's aluminum coating must be reapplied every two years to maintain the reflectivity needed to capture light signals from across the universe.

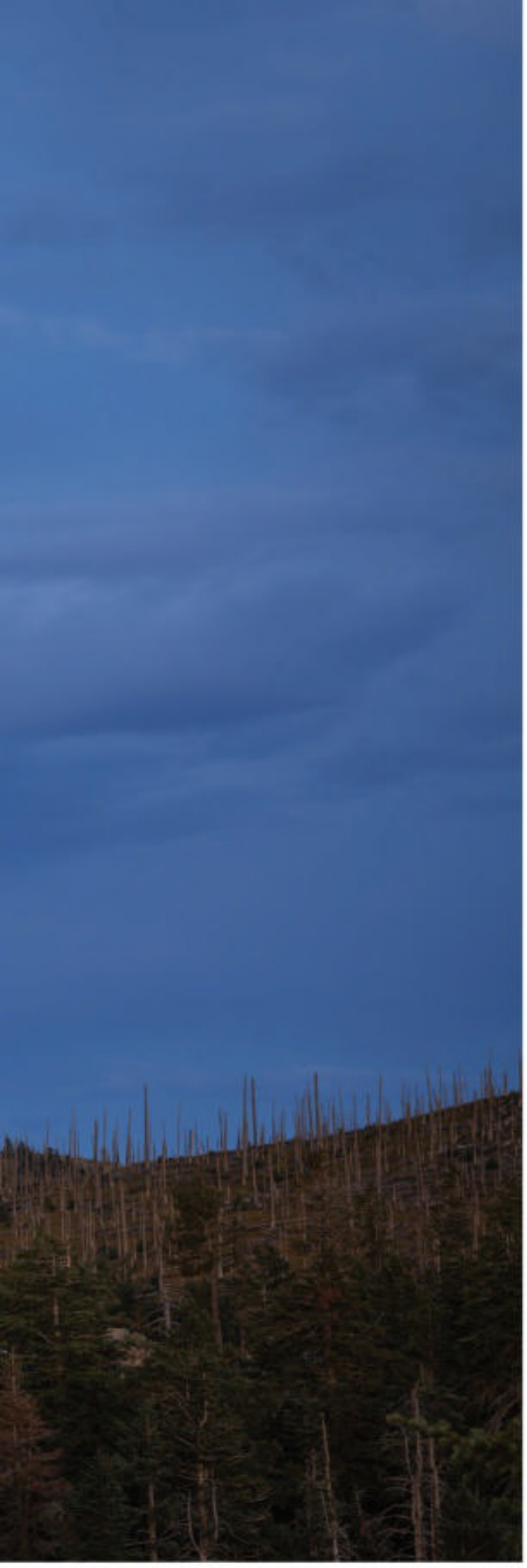
OF ALL THE NEXT-GENERATION GLASS advancements, it was one that centered on E6 that captivated me and prompted my visit to the Chiba Kogaku factory. After the clay pot was smashed to extract the chunk of E6, technicians then used blowtorches to slice it into shoebox-size blocks, which would then be packaged and shipped to a laboratory nestled beneath a football stadium in Tucson, Arizona.

There, the world's only customer of E6, an astronomer named Roger Angel, would use it to build the biggest telescope mirrors in the world. When completed on a mountain peak in Chile's Atacama Desert, the Giant Magellan Telescope, as it's known, will enable scientists to observe details of the cosmos never glimpsed before.

The secret to the Giant Magellan's ability to see more than any previous telescope is its huge mirrors—each 27.5 feet in diameter, roughly the width of a tennis court. Mirrors are the key to the optical strength of a reflecting telescope, which relies on them to gather light. So the larger the mirror, the more light it can gather from a distant object such as a star or planet.

"We chose eight meters because it's the size of the freeway," Angel told me, alluding to the journey on a tractor trailer that the mirrors must make from his lab to the port in Houston where they're loaded onto ships that take them to Chile.

But astronomers have long been confounded



The twin 27.5-foot mirrors of the Large Binocular Telescope—the world's largest single-piece telescope mirrors—work together to study everything from celestial bodies in our solar system to distant galaxies and black holes. The Giant Magellan Telescope, now under construction in Chile's Atacama Desert, will feature seven similar mirrors, which will provide astronomers with enough clarity to study planets orbiting other stars for signs of life.

by the challenges of casting large mirrors; the bigger they got, the heavier and more unwieldy they became. Angel solved this by using a mold based on a honeycomb, which greatly reduced the mirror's weight while increasing its strength and rigidity. He and his colleagues also devised a way to spin the glass as it melts to give it a slightly concave shape, reducing the time needed to grind and polish it.

Angel recognized in the 1980s that advancing the field of astronomy would require larger telescope mirrors that could capture more detail. If no one else was manufacturing the mirrors he needed, why not make them himself? A former student likes to tell the story about how, back then, Angel used a small kiln to fuse two Pyrex bowls together to prove the basic concept that he could melt the type of glass he'd need for big mirrors. "I take comfort from the fact that previous great scientists, including Galileo and Newton, actually made their own telescopes," Angel says.

Last October I was invited with other members of the media to the Mirror Lab—a cavernous facility constructed on what used to be a parking lot beneath the east stands of the University of Arizona's football stadium—to watch the "high fire" moment when the furnace would reach peak temperature to cast the Giant Magellan's seventh and final mirror. Weeks before, a team had carefully loaded 19 tons of E6—thousands of the shoebox-size blocks—into the circular furnace, about the size of a small swimming pool.

After casting, the glass will be slowly cooled for 85 days, then ground and polished for about a year before an aluminum coating is added to make its reflective surface.

Angel, who's 83, stood by himself, his arms behind his back. He seemed lost in thought watching the birth of his latest creation, possibly dreaming up a new challenge. Magellan is just part of a continuum of revolutionary, some might say outlandish, projects, one idea feeding the next. He has looked into building a cloud of billions of small sunshades that would be launched into space to reduce global warming. He's interested in developing flexible mirrors that could concentrate sunlight to produce the high heat needed to make cement, thus reducing the carbon footprint of the world's most popular building material. He's also investigating ways to build an observatory on the moon's south pole.

These ventures, however, take a back seat to the Giant Magellan Telescope. When astronomers finally begin using it to survey the heavens—expected sometime around 2029—the mirrors will be able to measure distant planets passing in front of stars to a degree never before achieved, allowing scientists to determine their temperatures and whether they contain gases like methane and oxygen, possible signs of life. "It would be the discovery of the century," Angel says.

I could hear the whirring as the furnace spun. I imagined the E6 inside, melting into a huge mirror that would make such a discovery possible. It felt like I was witnessing something historic, something that could change everything. □

Senior science editor **Jay Bennett** wrote about the search for early galaxies in the October 2023 issue.

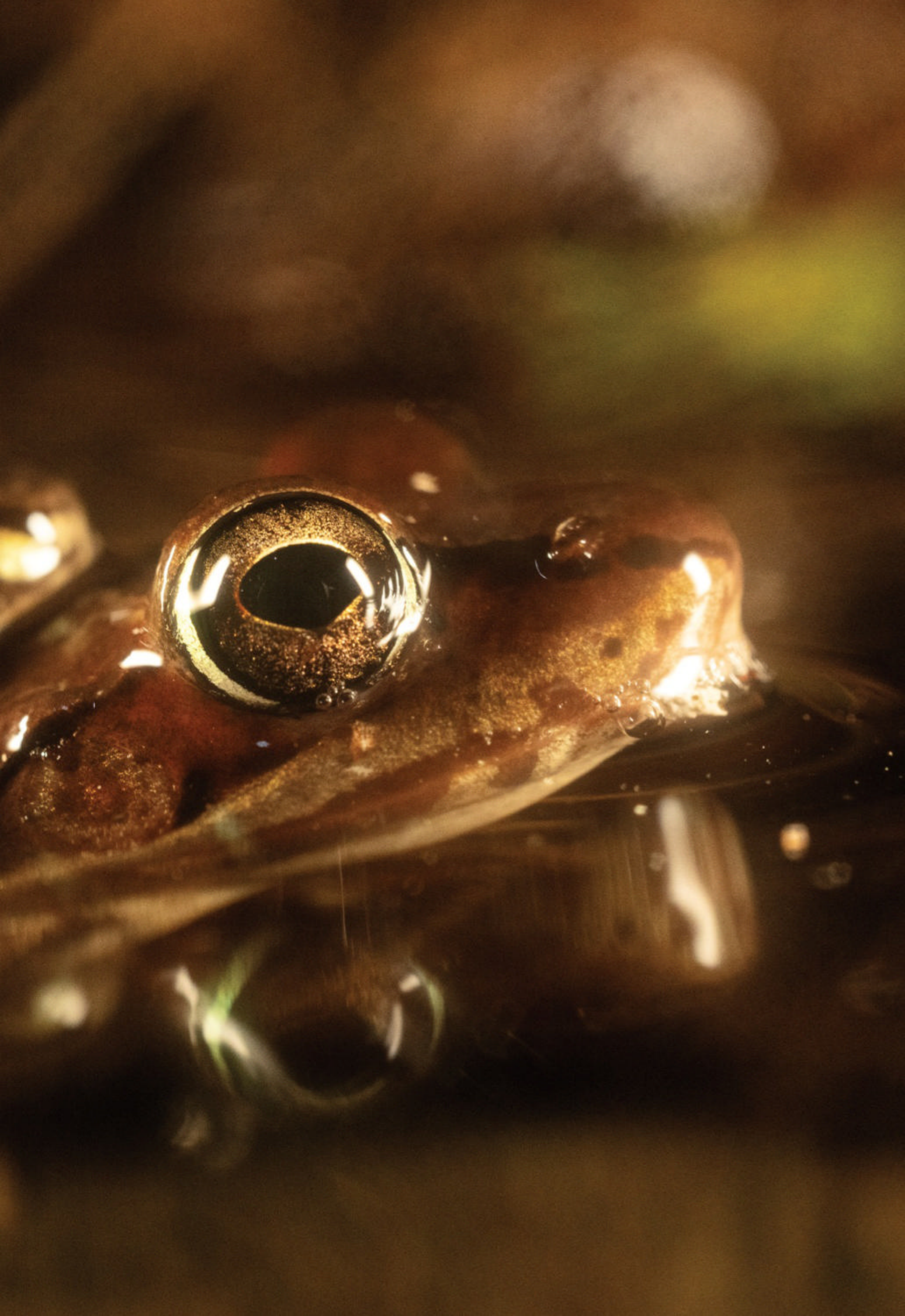
A dappling of spotted salamander eggs, some infused with the algae that will help sustain them as they hatch, floats near the surface of a vernal pool in Maine. Fed by rainwater, seasonal, pop-up ponds are vital to the forest ecosystem.

BY **SUSAN HAND SHETTERLY**
PHOTOGRAPHS BY
TRISTAN SPINSKI

Where the Forest Springs Eternal

Then they vanish—until it's time for the annual cycle to begin again.

A pair of wood frogs mates in the shallows of a vernal pool during the annual breeding migration in Maine. Steady evening rain and temperatures around 40 degrees prompt masses of frogs and salamanders to thaw and leave their winter burrows.

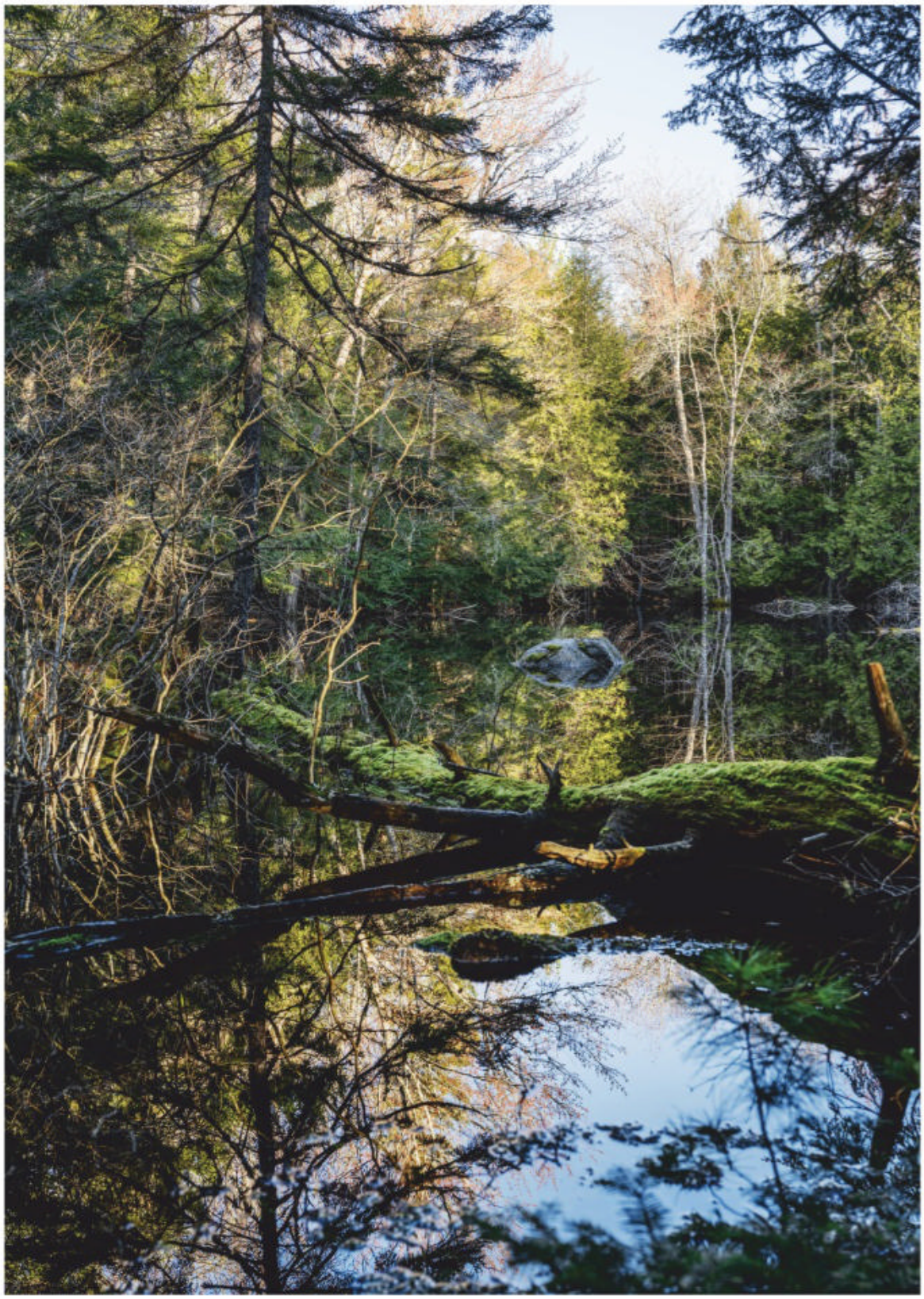


I FOLLOWED A PATH made soft by years of fallen needles through a hemlock forest. Up ahead a glow looked as if a fire had been struck in a patch of forest duff. It was sunlight, not fire, shining from an opening in the trees where a small pool bounced the light back into the air. This shallow saucer of water was a vernal pool. It was what I'd come for.

The day was late in spring, a warm afternoon, and the water in the pool had already begun to contract. Vernal pools depend primarily on rainwater and the runoff from the forest uplands. They have no permanent inlet or outlet. They are small, just a few feet deep, and often strung along the forest floor like reverse archipelagoes. As the season heats and spring rains end, they lose water to evaporation and to the roots of the surrounding trees and bushes. Most pools dry out by late summer. This is an essential quality of a vernal pool. Fish can't survive a dry-out, which means that the larvae of frogs, salamanders, all sorts of insects, and more, get a better chance to grow up.

GARTER SNAKE

Aram J.K. Calhoun and her husband, Malcolm (Mac) Hunter, both professors emeriti in the University of Maine's Department of Wildlife, Fisheries, and Conservation Biology, are dedicated to studying the enormous ecological impact of these tiny, ephemeral pools.



SPRING

SUMMER

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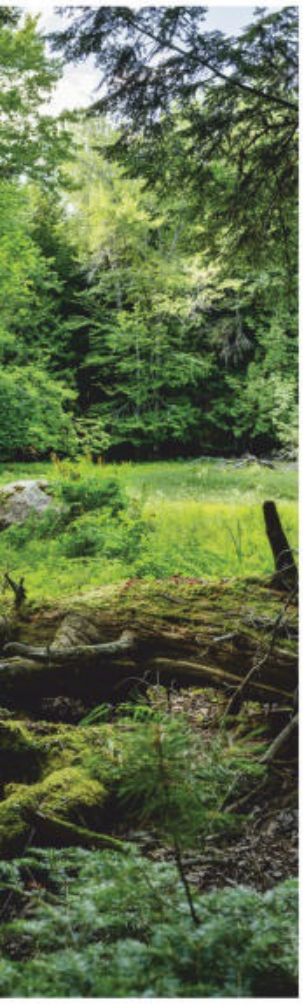
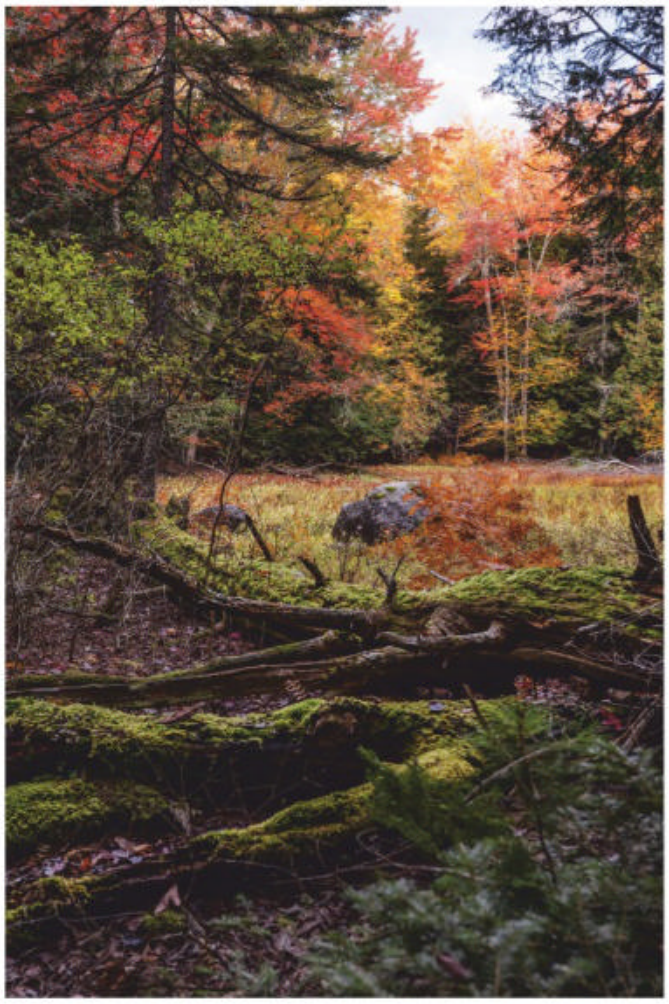
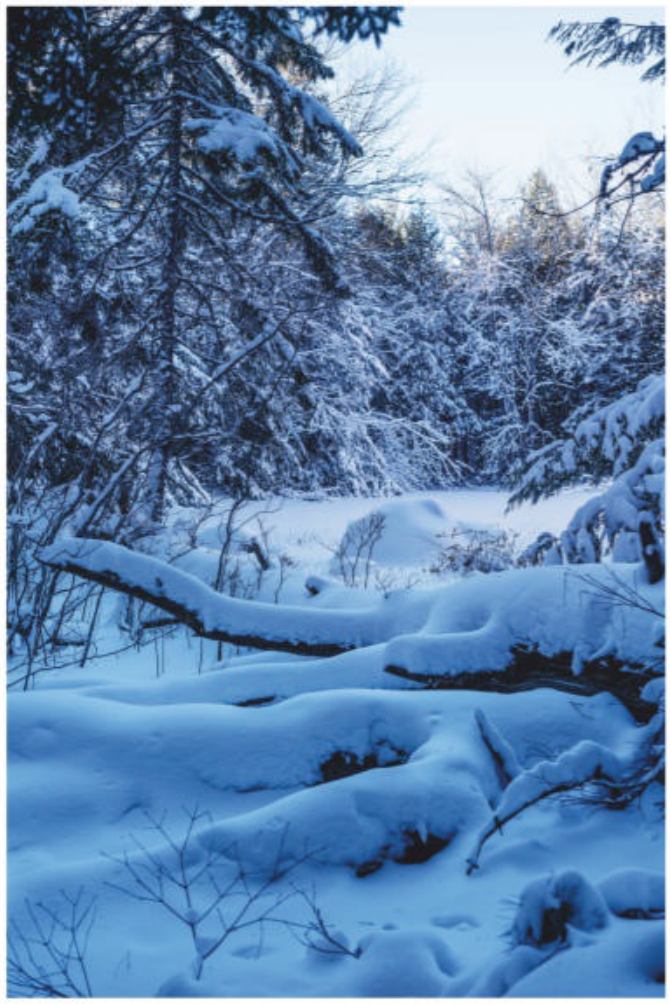




FALL



WINTER

nd species rstand arts that

Most vernal pools swell and surge to life each spring, only to dry down during the summer and go dormant in the winter. This annual cycle ensures that the temporary hatcheries remain free of fish, creating an ideal breeding ground for amphibians. In Maine, wood frogs, spotted salamanders, blue-spotted salamanders, and fairy shrimps are four species that are specially adapted to thrive in vernal pools, which also become crucial water holes and feeding grounds for surrounding wildlife.

From the water to the land and into the air, those that live in these forests carry a bit of a woodland pool within them.

Midsummer water lilies sprout within many pools, providing shade

BLANDING'S TURTLE; WOOD FROG

Here in the northernmost corner of the Northeast, a wedge of glacial ice a mile high reached its heft about 20,000 years ago. Tending east, it left kettle holes, sculpted ridges, rocks the size of boxcars, and hollows of clay and moraine. These woods bear the memory of that ice. They are quick with streams, marshes and ponds, and an abundance of seasonal pools. It's as if that long-ago ice willed us the gift of water.

With their spongy margins and their uplands that contain both damp and dry refugia, all indispensable parts of one system, these pools deliver an outsize burst of life to the forest. The relationship between the trees and the pools is tightly woven: The trees provide some shade to prevent a pool from drying out too soon, and they drop needles and leaves and branches into the water, rich feasts for bacteria and insects such as caddis fly larvae that in turn become food for others. Birds and bats that shelter and nest in the surr when adul onto the la On it goes. the air, tho of a woodl

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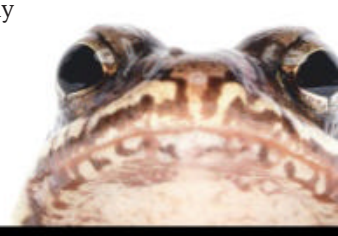

e for other aquatic inhabitants.

A spotted salamander deposits her egg cluster on a submerged stick during the spring mating season.

ounding trees feed on insects, and
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From the water to the land and into
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ith hundreds of lives in their warming,
g waters, people walking through the
n pass them by with hardly a notice.
repossessing pools hide much of that
rgy below the surface. It reminds me
of whales. How would we know that
they needed our protection if all we
saw were the waves?

I DRAW A SMALL NET carefully along the bottom of a vernal pool in spring, lift it, and invert it into a glass bowl. All sorts of species emerge.

Many animals found in the pools can live well in other bodies of water, but a few are uniquely adapted to them to complete their life cycles. As April arrives and ice melts and rains sweep across the land, fairy shrimps hatch in the ponds and swim beneath a pane of thin spring ice. These crustaceans, about an inch long, paddle with ventral side up, raking the water with their abdominal appendages, which allow them to breathe and gather food as they propel themselves through the water.

Fairy shrimps have evolved not only to anticipate a summer dry-out but to require it. When a female expels fertilized eggs from her pouch, they sink to the bottom, grow for a few days, and stop. The tiny hard-shelled eggs rest in the muck of a drying pool blanketed by layers of leaves and other debris. They will hatch and grow when the rains return, their lives in sync with the pool's seasons.

Not all fairy shrimp eggs, or cysts, hatch in a given year. They can wait 10 or 20 years, and some researchers surmise that they probably can lie in the mud of a pool for a century.

On a night of cold spring rain, wood frogs rise out of their long dormancy. The frogs spend the winter in shallow depressions, under leaves, or within fallen trees lying on the forest floor. Slick with rain, they hop toward pools that are sometimes still rimmed with ice. Researchers often refer to them as "tough" because they can live as far north as the Arctic Circle.

Wood frogs don't need to survive the cold below the frost line. When temperatures drop, their livers release a rush of glucose, which joins high urea levels in the bloodstream. This cocktail floods tissues, limiting the icy damage. The frogs are literally frozen. And appear quite dead.

The mixture sustains them through the vagaries of early spring. Often the first amphibians to reach the breeding pools, they can thaw and freeze and thaw again. Male wood frogs call to females in rough, ducklike voices. The call alerts

Teeming With Tiny Life

Vernal pools, from the Latin word for "spring," are small bodies of ephemeral waters, formed in shallow depressions and bursting with life soon after snowmelt or spring rains. Found across the U.S. and in many parts of the world, these ecosystems are dynamic and seasonal. As a pool dries, many of its animals migrate far into surrounding forests—if not obstructed by human development—and return the next year when the pool fills once more.

SMALL POOLS, BIG CONNECTIONS

Hundreds of species of animals, mostly migratory, can be found in vernal pools. Certain frogs, fairy shrimps, and salamanders largely depend on the pools for breeding.

- Life span
- Average number of eggs laid
- Typical adult migration distance
- Size

BREEDING ZONE

The seasonal forest pools host aquatic-breeding invertebrates, amphibians, mollusks, and crustaceans—all free from predation by fish.

FOREST REFUGE

Leaf litter and fallen trees on damp forest floors shelter amphibians and reptiles as they migrate to foraging and hibernating upland habitats.

WILDLIFE OASIS

Vernal pool waters and their concentrated assemblage of prey are a source of food, water, and resting sites for myriad forest animals.

Fairy Shrimp*

50-90 days | 100s
None | 0.5-1 inch

In the dry season, eggs lie dormant. Viable for years, the crustacean eggs hatch when pool waters return—and for a life span lasting only as long as the pool does.

Wood Frog

3-5 years | 1,000
435 ft | 2-3 in

Their bodies are adapted to partially freeze when hibernating under forest leaf litter. After waking, adults travel to pools to deposit egg masses that soon turn into tadpoles.

Spotted Salamander

15-20 years | 20-100
390 ft | 6-8 in

These amphibians emerge from upland burrows to deposit eggs on submerged stems. Eggs must develop from larvae to juveniles before the pool dries.

CANOPY PROTECTION

Intact canopy cover helps retain the humid climate that frogs and salamanders, which have moist, permeable skin, require to survive.

DEVELOPMENT

Rainy-night, early spring migrations back to pools of their birth expose animals to vehicle strikes and deicing chemicals on roads.

POOL NETWORK

Most animals return to their natal pools, but some juveniles disperse to other waters, spreading their genes across a larger landscape.

*FAIRY SHRIMP *(EUBRANCHIPUS VERNALIS)*, WOOD FROG *(RANA SYLVATICA)*, AND SPOTTED SALAMANDER *(AMBYSTOMA MACULATUM)* RANGES SHOWN

MONICA SERRANO, KATIE ARMSTRONG, PATRICIA HEALY, AND EVE CONANT, NGM STAFF. ART: KOMA ZHANG. SOURCES: ARAM J.K. CALHOUN AND MALCOLM (MAC) HUNTER, DEPARTMENT OF WILDLIFE, FISHERIES, AND CONSERVATION BIOLOGY, UNIVERSITY OF MAINE; IUCN; INATURALIST

Vernal pools are fleeting oases that many species depend on, including (clockwise, from top left) a juvenile painted turtle, a ringed bog haunter (a rare dragonfly), a barred owl, and a blue-spotted complex salamander, all found in the Northeast. A portrait (opposite) reveals a wood frog during the breeding migration. Such species are a good indicator of a pool nearby, although they will travel up to thousands of feet to reach one.

A school of tadpoles swirls amid sphagnum, leaf litter, and fallen tree branches in a vernal pool in early spring. These swimmers feed on algae, bacteria, and more and can become food for other animals. As adults, most frogs will return to their birth pools to breed.

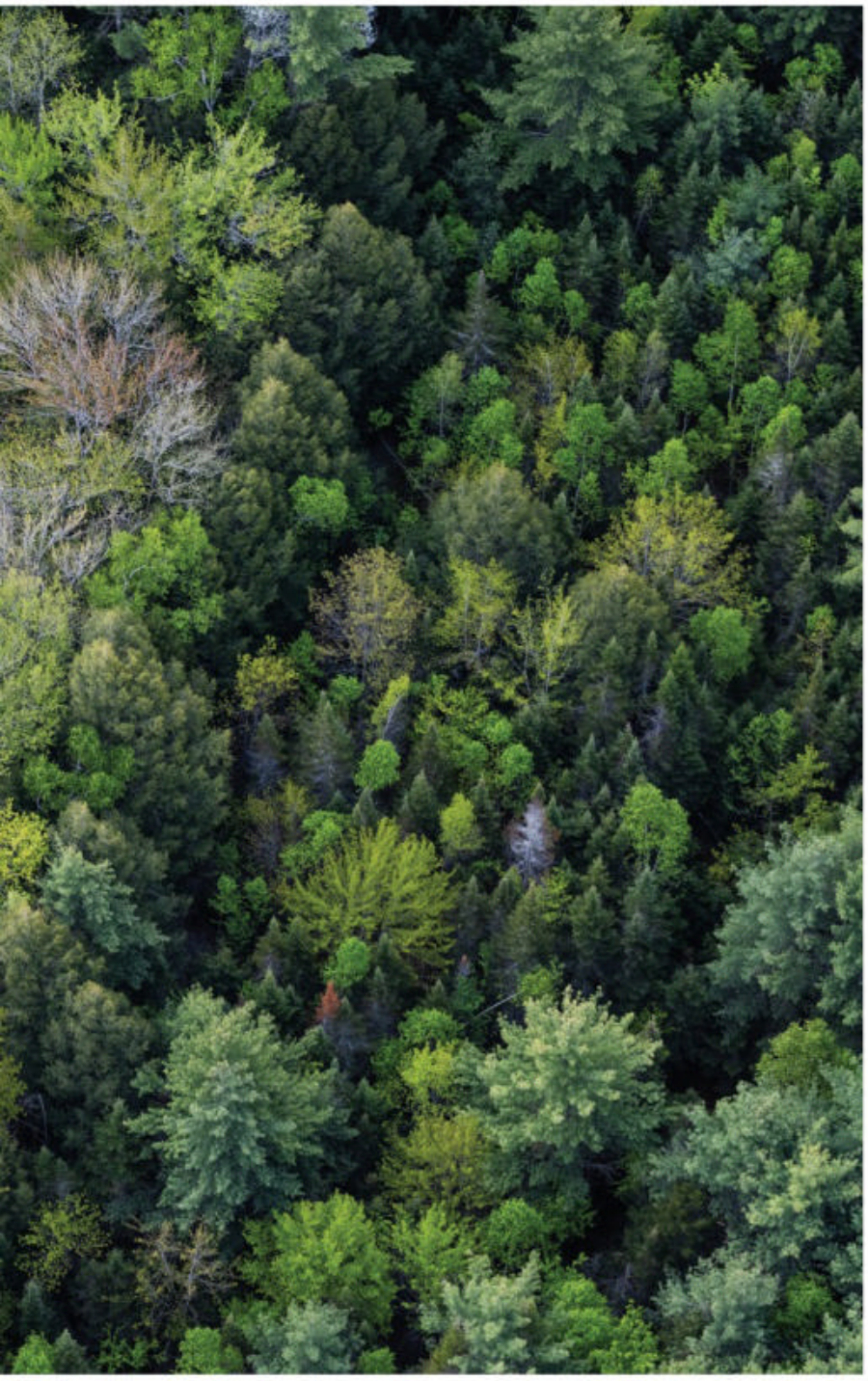
An aerial view shows a large vernal pool and the surrounding landscape in Aurora, Maine. The state has more forested area—nearly 90 percent of the land—than any other state in the country.

the females that the spring ritual has begun, and many hungry predators that have endured a long winter also hearken to the cacophony. This ritual, full of quacking, splashing, and shrieking as males struggle with one another to grasp females in a mating hold, is brief. The females expel round masses of eggs. The males, tight to their backs, release a cloud of sperm to fertilize them.

Spotted salamanders arrive at about the middle of the frog mating ritual. These members of the mole salamander family spend almost their entire lives below the surface of the land, under mosses and leaves and tree bark, in the tunnels left by long-dead roots, and within the decomposing trunks of fallen trees. Unlike the wood frog, the salamander overwinters below the frost line, often in the deep burrows made by short-tailed shrews.

Their mating ritual is performed underwater, a mute congress of many, as the males place their white spermatophores, pyramid-shaped sperm packets, on a leaf or twig on the pool bottom. A female passes over them, enveloping one into her cloaca for fertilization. Their egg masses, attached to sticks and stems, are kidney-shaped, smooth, and somewhat translucent, encased in an outer layer of firm jelly.

As the salamander larvae grow, they feed on insects and small crustaceans and wood frog tadpoles, and each other. The tadpoles prey on amphibian eggs and carrion, but their diet is primarily algal and bacterial film they scrape



from the surfaces of plants and other pool detritus. Everyone is eating or being eaten, and most, but not all, are racing against the summer drawdown.

Nearly all mature wood frogs and spotted salamanders aim to return to their birth pools to breed, but a few juveniles are pilgrims. Each year a number will metamorphose, climb out of their pools, and walk away, carrying their genetic infusions to farther ponds on the forest floor.

VERNAL POOLS CONTINUE to be overlooked. Their best advocates are biologists who study them and people in towns and villages willing to make the case to protect them against development. A growing movement in the Northeast brings local citizens out at night in the first spring rains to assist amphibians crossing busy roads to their natal pools. To cradle a salamander or a wood frog in the cup of your hand on a cold night is like holding a living icicle.

Some people take it upon themselves to map the pools, checking for species and making detailed notes of the surrounding landscapes. Those who do this work know that to save a pool without protecting its broad edges as well as its uplands is to save very little.

A persuasive voice in the effort to teach what is known about vernal pools and how to save them, Aram Calhoun dedicates her career to these reserves of temporary water. She is a seasoned wetlands biologist and environmental educator. Her writing has become part of wetlands landscape policy that resonates in Maine and beyond. Calhoun has also worked alongside biologists in the Department of Natural Resources of the Penobscot Nation to build a case for mapping vernal pools on tribal land.

"The Penobscot Nation Department of Natural Resources has just received five million dollars in funding from a public-private grant program to support work to map vernal pools on tribal trust lands," says Ben Simpson, the wildlife resource manager for the nation. "These funds will help us map critical habitat the tribe is determined to protect."

My neighbors and I learn from efforts such as these. Together we trudge out to our back road in the rains of April with flashlights and headlamps to greet frogs and salamanders making their slow way through the dark to the pools where they began. It's a celebration of what it means to be alive, to share where we live with species other than our own. ▯

Photographer **Tristan Spinski** lives in Maine. This is his first feature for *National Geographic*.

BY TAYLOR SISK

PHOTOGRAPHS BY LYNN JOHNSON

Bringing Them Home

WHEN CHILDREN FACE LIFE-THREATENING DIAGNOSES, THE GOAL IS CLEAR: PUT FAMILY FIRST.

Jill Rachau's daughter Emma Cromlish was born with multiple rare genetic syndromes. But thanks to a hospital program in Pittsburgh, Emma and Jill are able to enjoy time together in their front yard, away from a medical setting.

Emma has a blast with youngest brother Chance (seated next to Emma) and her mom at Kennywood amusement park, West Mifflin, Pennsylvania.

ON A MILD SATURDAY MORNING IN EARLY JUNE, Jamie Tezbir braced herself for a grievous decision. She was making her second trip to the emergency room in a week. Hospital runs had become routine for Jamie and her husband, Don, for nearly a decade. But this time felt different.

Their son Jackson, then nine years old, had been born with lissencephaly, an incurable brain malformation that triggers frequent seizures. Through the night and into that morning, the attacks had come every 20 minutes. And now his breathing was in severe distress. Jamie and Don had recently signed a do-not-resuscitate order; should Jackson go into cardiac arrest, it would be abided by. But were they receptive to intubation? ICU doctors and anesthesiologists stood ready. "It was one of those scary moments," Jamie said. This, she feared, "was what the end would look like."

As has become her practice in fraught moments, Jamie called Carol May, director of the Division of Palliative Medicine and Supportive Care

Emma, Age 3

Emma and her family have spent countless hours at UPMC Children's Hospital of Pittsburgh, where she has had several close brushes with death. "We can go from giggling, laughing, playing to checking out because she's in so much pain," Jill says. On good days, Emma sasses the doctors and blows the nurses kisses. On harder days, she has her dad, Gordon Cromlish (middle), to calm her during a scan, and doll Molly to hold as she uses an oxygen mask to offset sleep apnea.

Jackson, Age 9

Cassie Grassmyer (seen here with Jackson) has been a pillar for Jackson's mom, Jamie Tezbir. In 2020, Cassie lost her son, Jack, to lissencephaly—the same incurable brain malformation afflicting Jackson, which requires periodic oxygen therapy (at far right). Cassie has helped prepare Jamie for the end stages. "We don't know how long we'll have with him," Jamie says. "But having a plan in place makes me feel a lot better."

Stevie, Age 3

Erica and Rich Kruger's daughter, Stevie (far left, with Erica), was born with the chromosomal condition Trisomy 18. When the Krugers made the decision to remove her from a ventilator at UPMC just after birth and to decline invasive procedures, they were told it wasn't likely Stevie would live even a few hours. She's now three. Her community celebrates her life with identical Trisomy 18 tattoos.

Nevaeh, Age 20

Raynell Lester is clear on what she wants for her daughter Nevaeh (at right, with sister Durrae, standing): no more extreme interventions. On the porch with them are a neighbor and Nevaeh's baby niece, Adielle. Hospital stays take a terrible toll on Nevaeh, who has a severe form of epilepsy, and Raynell has chosen to refrain from major procedures. Medical director of the UPMC supportive care team Scott Maurer told Raynell, "You're putting her first, and I think that's the greatest gift of love" a parent can give a child.

at UPMC Children's Hospital of Pittsburgh. A great many advances have been made in medical care that allow children with complex chronic conditions to live longer. But some families, like the Tezbirs, are choosing to prioritize quality of life. May's team provides palliative and hospice care, which includes liaising with specialists and coordinating logistics for home-based care. They are there to advise, to advocate, to help realize a family's wishes for their child.

Palliative care is about keeping kids comfortable while managing their symptoms. Hospice is founded on a philosophy of "neither hastening death nor prolonging life," said Scott Maurer, the medical director of UPMC Children's Hospital's supportive care program. It focuses on the child's "physical, emotional, social, and spiritual comfort." May, Maurer, and their colleagues believe that, in most cases, home is where comfort and well-being are best nurtured.

Bedrooms can be outfitted as mini-ICUs. A specialist is a telehealth screen away. A return to routines is encouraged: the family as one.

On a Friday afternoon in August 2022, Maurer was making his hospital rounds. "Oh my gosh," Maurer said to Kylie McMullen, age six at the time. "We're twins." They'd just learned that both are partial to the crust of pizza. Also, both love unicorns. "A match made in heaven."

Kylie had been diagnosed that February with stage 4 alveolar rhabdomyosarcoma. At the time, Maurer estimated Kylie's chances of surviving it at little better than 10 percent. She had suffered mightily from secondary issues: a collapsed lung, the trauma of a bone marrow biopsy. In consultation with the doctors, her parents, Sean and Kirsten, had decided to pursue a form of chemotherapy and bring Kylie home, with hospital visits as needed.

By autumn of 2023, Kylie was doing remarkably well and was able to focus on the important things, like what she was going to be for Halloween. "We've been throwing around lots and lots of ideas," Kirsten said. A witch was one contender, but Mulan won out. Kylie's final IV chemo treatment was scheduled for November 9,

after which she'd move to daily oral doses. If her scans continued to look good, she'd be treatment free.

For Kylie's younger sister, Quinn, this experience has been disorienting. You can see Quinn's trying to process what her family is going through, Sean said. Back in the worst of it, she would say Kylie was "big sick."

"Honestly," Sean said, "I haven't heard Quinn use 'big sick' since probably last spring [in 2022]."

Like many palliative care programs, UPMC's traces its history to the heart and mind of a nurse. When May was 17, her grandfather, who had been diagnosed with lung cancer, was at home for his final days. She knew then she'd found her calling. This, she told herself, is how a loved one should pass: embraced in the familiar, surrounded by family.

Pediatric palliative care is a balancing act. "It's OK to hope for a miracle," Maurer said, but "if I stop asking after they tell me their first hope—which is always the miracle—then I'm not going to understand the values that are driving them." All decisions must be filtered through those values. And it's a partnership.

Jessica Mitchell's daughter, Genivive, now eight, was exposed to E. coli in the womb, which led to the development of cortical dysplasia and epilepsy. Unable to speak, she communicates through subtle means. Is she sensitive to her mom's disquietudes? "Oh God, yes," May acknowledged during a Saturday visit to check in on the well-being of mother and child. "When Jessica wants to openly express herself—in many different manners—she does so." Jessica smiled. She's a fierce advocate for her daughter.

Jessica said she is always alerted to May's arrival by the authoritative click of heels, a detonation of laughter. Though the sounds are ever welcomed, she much prefers to hear them emanating from the sidewalk outside her Scottdale, Pennsylvania, apartment than from a UPMC corridor. Being in the hospital aggravates Genivive. For Jessica, it's unsettling. "I know she's going to die there eventually," Jessica said. "You're not in a peaceful place [mentally]."

Genivive recently went more than 16 months without a hospital visit, which Jessica called "a world's record" for her daughter. "I'll put it

Kylie, Age 6

For Kylie McMullen (bottom, at center), the journey from stage 4 alveolar rhabdomyosarcoma to what her mom, Kirsten, calls "almost normal," has been long. Seeing Kylie's transformation through photos "really puts [the past year] into perspective," says Kirsten. From top: Kirsten (with phone) makes a mid-procedure video call to husband Sean; Kylie builds a bond with brother Cam (at right); a family portrait, with Sean holding daughter Quinn.

UPMC's Maurer (kneeling) takes a personal approach with patients.

this way: I take care of Genivive, but Carol keeps her alive," said Jessica. "What can I do for you today?" May is likely to say upon greeting them. And in parting, "What more can I do?" Though there may be no immediate needs, May is on 24/7.

The Tezbirs can testify to May's gift. Intubating Jackson after his scare in June ultimately proved unnecessary; his condition was deemed recoverable. May was there on the phone, consulting and calming Jamie while coordinating with one of the doctors in the room. "She talked me out of my panic," Jamie said.

Jackson returned home three days later. But as his need for medications to control his seizures increases, Jamie said, those "glimpses of enjoyment, of happiness," are vanishingly rare. His mom and dad are exhausted, in every conceivable sense. "I want this to be over," Jamie said, "but I don't want to lose him ... I don't know what it will be like to not wake up to him, or hold his hand, or smell his hair."

Jamie and Don know the next critical moment is likely near. They take solace that the UPMC team sees Jackson not as a neurology or pulmonology patient but as Jackson, their child. The team has offered the "grace," Jamie said, to accept what she and Don ultimately decide is best for Jackson. □

Taylor Sisk is a Nashville, Tennessee–based health care reporter focused on policy's human impact.


LOVE

Genivive, Age 8

Carol May (at left), UPMC's director of the Division of Palliative Medicine and Supportive Care, first met Genivive Mitchell shortly after Genivive's birth, when her major organs were failing and she was taken by ambulance to UPMC. In the years since, May has worked with Genivive's mom, Jessica, to provide the care that mom and daughter need. This entails advocating for Genivive in the hospital, sorting medicines at home, and everything in between.

NEXT PHOTO

Genivive gets out and about quite frequently, but this trip is different. At Southmoreland Primary Center, in Alverton, Pennsylvania, she meets the children who would be her classmates. The kids are initially hesitant, unsure. But with a bit of nudging, they lean close with observations and questions. For the class, it's a chance to understand and appreciate how unique, and similar, we all are.


WILD


ADVENTURE
ROCKE
BRIGHT &
KEEP ON

GUNUNG PALUNG BEGAN AS A REMOTE INDONESIAN FOREST RESERVE. TODAY IT'S GROWN INTO A SPRAWLING NATIONAL PARK THAT PROTECTS SOME OF THE WORLD'S MOST BIODIVERSE RAINFORESTS AND THE CREATURES THAT CALL THEM HOME.

BORNEO'S WILD GREEN HEART

BY **JENNIFER S. HOLLAND**

PHOTOGRAPHS BY **TIM LAMAN**

A female orangutan forages for ripe figs in the rainforest canopy of Gunung Palung National Park in Indonesia's West Kalimantan Province. The park's 417 square miles support about 2,500 of the critically endangered apes and thousands of tree species.

RUSSELL LAMAN, WITH DRONE PILOT TRI WAHYU SUSANTO

A Bornean horned frog nearly disappears in leaf litter, its camouflage affording an advantage over insects it hunts. The frog's distinctive *honk* is one of countless calls filling the rainforest's diverse soundscape. While this creature is found on other nearby islands, more than 70 percent of Gunung Palung's amphibian species live only on Borneo.

DANGLING ON A ROPE SOME 40 FEET UP, AMID A LABYRINTH of leafy tree limbs, I looked down and questioned my sanity for asking the two men far below to hoist me into the canopy of this rainforest. One of them, photographer Tim Laman, had tied a line to an arrow and shot it over a high bough. Then he and his assistant rigged a pulley system to lift me to a place few humans get to visit. With each of their heaves, the rope squeaked and the branch above bounced precariously.

The aim of this adventure was to reach a high crotch in a 150-foot-tall *Shorea* tree, whose genus includes some of the world's tallest. A spot among its high branches would offer an ideal view of one of the last remaining intact lowland rainforests left in Southeast Asia. Located just below the Equator, Gunung Palung National Park is a 417-square-mile protected area that encompasses the Palung and Panti mountains in the Indonesian part of Borneo. (The island is divided among three nations: Indonesia, Malaysia, and Brunei.) An area around Mount Palung was first designated as a natural reserve in 1937; over the years its borders were stretched, and in 1990 the Indonesian government designated it a national park. Today it covers nine distinct forest types stacked one atop another across a series of steep slopes, moving up from mangrove and peat swamp to mossy mountaintop forest.

Once the guys hauled me as high as they could, the rest of the climb was on me. It was agonizingly slow, nothing like the easy scramble I'd seen other primates make into the treetops. As I inched up the rope, my arms ached, my left sock squished with blood from a leech bite, and I was marinating in sweat.

But it would be worth it, I reasoned, because of what lives in that green world overhead. All week I'd reveled in the cackles of leaf monkeys, hoots of gibbons, and barks of macaques, plus choruses of birds and frogs—all backed by the hums and

Red leaf monkeys, including this female with her infant, eat figs year-round and other fruits as they ripen. The primates, known for their cackling calls, have adapted well to the young secondary forests that have filled in where old-growth trees were cut down.

The nonprofit National Geographic Society, working to conserve Earth's resources, helped fund this article.

NGM MAPS

whines of insects. Since the canopy is home to these musicmakers, I hoped to glimpse something animal from a perch at their eye level.

Truth be told, I was most excited to meet the island's biggest stars: the orangutans. The flaming-orange-haired primates are the only great ape native to Asia, and the Bornean orangutan, *Pongo pygmaeus,* has long represented the soul of Gunung Palung while playing a crucial role in the health of its forests. Some 2,500 of them roam these treetops, a healthy number considering they're critically endangered. And when Laman mentioned he could get me up into their domain, I was game.

At about a hundred feet, I was well below the top of the canopy but high enough that I could see the curve of a fog-shrouded mountain rising over densely forested parkland. I swung myself into the fork of two large limbs and settled in to admire the view and, with luck, spot something furry or feathered. Time passed. I gazed and listened expectantly. The branches gently swayed, and the whisper of leaves taunted me; otherwise, all remained quiet. More time passed. No glorious birds came to feed; no chattering primates swung by. Even the insects seemed to be on a break. I wasn't surprised—the time of day and dearth of fruit in this tree weren't ideal for wildlife spotting.

Still, I was a bit disappointed that nobody was home.

Gunung Palung lies in Borneo's swampy southwest, within the Indonesian province of West Kalimantan. For scientists, the park's remoteness and limited tourism are pluses: Gunung Palung presents a veritable time capsule of what the island was like for millennia. By exploring this primal world directly, I'd hoped to view its wonder with fresh eyes and discover more about how life here continues thriving.

Some of the biggest clues were right in front of me, but I'd already missed them.

BORNEO'S RAINFOREST HAS BEEN EVOLVING FOR MILLIONS OF years, a process that has yielded a bounty of unique flora: Consider its more than a thousand types of orchids, or its dozens of kinds of carnivorous pitcher plants, or its 3,000-plus tree species, including the towering yellow meranti that can grow taller than the Statue of Liberty.

Somewhere out there are clouded leopards, pygmy elephants, flying foxes, flying frogs, flying lemurs, flying snakes, nearly 700 species of birds, about a hundred species of bats, and more than a thousand kinds of ants. And let's not forget the gazillion other insects, reptiles, amphibians, spiders, fungi, and microbes. It's a living forest and unlike any other on Earth.

Among the first botanists to inform the Western world's imagination about these marvels was an Italian named Odoardo Beccari, who visited the island in 1865. He was 21 years old and fresh from university when he arrived in Borneo to wander its "great forests." His account of those travels is filled with descriptions of otherworldly flora and other organisms. He encountered the massive *Rafflesia* flower, which featured nearly two-foot-wide scarlet petals and smelled like a rotting corpse, and a phosphorescent fungus that emitted enough light at night to allow him to read a newspaper.

To Beccari, the jungle seemed a riot of plants ruthlessly scheming and strategizing. He marveled at how orchids and other flowering plants made their way into the upper stories of the mightiest trees to reach the sunlight and used their brilliant colors, peculiar shapes, and powerful odors to attract insects that helped them pollinate and propagate. "To ensure success," Beccari wrote, "nature uses every possible artifice, every sort of deceit, every kind of cruelty."

The temptation might be to assume that this complex ecosystem flourished because there were no humans to disrupt it. But people have been living on Borneo for at least tens of thousands of years. The oldest known figurative painting—thought to depict a wild cowlike animal—was found in a Bornean cave and dated to at least 40,000 years ago. And as seafaring advanced, traders from throughout Asia, and later Europe, flocked to the island for its trees, minerals, and animals.

Today the list of resources extracted from Borneo reads like a modern plunderer's shopping list: timber, gold, diamonds, bauxite, coal, natural gas, and animals poached for the pet trade or traditional medicine. But the most devastating losses

A male great argus, one of the world's largest pheasant species—they can reach up to six and a half feet, beak to tail tip—woos a potential mate with a grand display of giant eyespot-covered wing feathers, plus a little dance. Males clear away sticks and leaves to keep a "stage" for performing.

have come with the conversion of forest to agriculture, including oil palm farms, which yield a substance widely used in packaged foods and other products. Drought-related fires have also depleted old-growth trees, and in the late 1990s, political and economic turmoil in the region fueled an explosion of illegal logging and mining. All told, it's estimated that Indonesian Borneo lost nearly a third of its forest from 1973 to 2010.

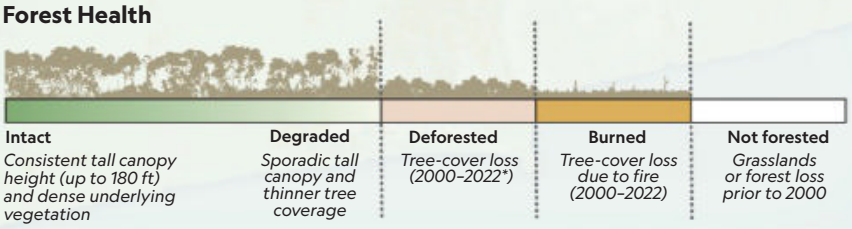
While the illicit timber trade has been reduced in and around Gunung Palung, the region's volatile history gives my visit a sense of urgency. Cheryl Knott, a Boston University primatologist who leads orangutan studies in the park, told me that while the forest inside its borders has recovered fairly well—especially with improved law enforcement and as research and conservation work has expanded and provided jobs to locals—"without continued vigilance, things could easily go the other way."

FOR MORE THAN THREE DECADES, CHERYL KNOTT and Tim Laman, who are married, have been coming to Borneo to study, photograph, and unlock more secrets about its wild things. In 1994 Knott began a long-term study of orangutan ecology and behavior at the park's small research station and has led the project ever since. She

A REFUGE OF INTACT FOREST

Starting in 1937, authorities began setting aside the first tracts of lush equatorial rainforest that would later form Borneo's Gunung Palung National Park. Today, even as human development has swelled around it, the 417-square-mile area holds some of Southeast Asia's most intact lowland rainforests. Along with local communities and scientists, the Indonesian government has worked to conserve this biodiverse region, home to soaring trees, extraordinary flowers, and endangered animals such as orangutans, helmeted hornbills, and proboscis monkeys.

Forest Health



Intact	Degraded	Deforested	Burned	Not forested
Consistent tall canopy height (up to 180 ft) and dense underlying vegetation	*Sporadic tall canopy and thinner tree coverage*	*Tree-cover loss (2000–2022*)*	*Tree-cover loss due to fire (2000–2022)*	*Grasslands or forest loss prior to 2000*

2 mi
2 km
N

Built-up area
Road

BORNEO'S FORESTS

Over the past 50 years, the island has lost more than a third of its old-growth forests. Most of its remaining intact forests exist in higher elevations. Gunung Palung is one of Borneo's few protected lowland areas.

Tree-cover loss
*2000–2022**

Remaining forest

National park

100 mi
100 km

South China Sea
Sulu Sea
Celebes Sea
Java Sea
Karimata Strait
Makassar Strait

Palawan (PHILIPPINES)
Mt. Kinabalu 13,435 ft 4,095 m
Kota Kinabalu
Sandakan
Bandar Seri Begawan
BRUNEI
MALAYSIA
INDONESIA
Tawi Tawi I. (PHIL.)
BORNEO
Central Highlands
Kuching
MALAYSIA
INDONESIA
EQUATOR
Pontianak
Nusantara (future capital of Indonesia)
Samarinda
Balikpapan
Mt. Raya 7,474 ft 2,278 m
ENLARGED AT RIGHT
Bangka
Belitung
SUMATRA
INDONESIA
Banjarmasin
SULAWESI
Mt. Latimojong 11,411 ft 3,478 m

Outside threats
Industrial farms cut down large areas of rainforest to grow crops, including oil palm, bananas, and rice. This process often involves draining peatland, which dries out the landscape and increases fire risk. Wildfires have caused damage and deforestation outside the park.

*MUCH OF THE OLD-GROWTH FOREST IN THESE AREAS WAS LOST BEFORE THE YEAR 2000.

SOREN WALLJASPER AND PATRICIA HEALY, NGM STAFF
SOURCES: ANTONIO FERRAZ, NASA/JPL; UCLA INSTITUTE OF THE ENVIRONMENT AND SUSTAINABILITY; JACKSON A. HELMS, LORAIN COUNTY COMMUNITY COLLEGE; CHERYL KNOTT, BOSTON UNIVERSITY AND GUNUNG PALUNG ORANGUTAN CONSERVATION PROGRAM; TIM LAMAN; GUNUNG PALUNG NATIONAL PARK OFFICE; NASA SRTM; OPENSTREETMAP; ALEXANDRA TYUKAVINA, UNIVERSITY OF MARYLAND; MATTHEW C. HANSEN, UNIVERSITY OF MARYLAND; GEOSPATIAL INFORMATION AGENCY OF INDONESIA

ONE PARK, MANY FORESTS

The park is composed of several distinct forest types, defined by the soils and environs they grow in. They range from salt-tolerant coastal mangroves to lowland peat swamps to the small trees of montane forests.

Peat forest converted to farmland, typically single crops (monoculture)

Access roads for agriculture

Sungai Mata

nal park

Simpang

Batu Barat

Batu Barat Ranger Station

Sungai Kubang tourist site

Matan

Lubuk Batu

2,060 ft 628 m

Even small mountains have intact forest.

Matan Ranger Station

Matan Jaya

stomary forests re managed by al communities.

Penjalaan Customary Forest

Rantau Panjang Customary Forest

Melbya

Cabang Panti Research Station
Scientists have been researching orangutans, rainforest ecology, and biodiversity here for four decades.

Reforested farmland connects areas of intact forest, creating a corridor for wildlife.

Forests at higher elevations and with more rugged terrain remain the most intact.

Bayun Sari

Research trails

Mt. Palung
3,661 ft
1,116 m

GUNUNG PALUNG NATIONAL PARK

FOREST REGROWTH

Rangkong Camp Research Station

Tanjung Gunung

Siduk

Laman Besolek tourist site

AGRICULTURAL AREA

Local farms using more sustainable techniques are less likely to degrade forest than large-scale farms.

Teluk Bayur

Sempurna Ranger Station

Sempurna

Jago Bersatu

OIL PALM CULTIVATION

Pangkal Tapang Ranger Station

Pangkalan Jihing Ranger Station

With remote sensing technology and community monitoring, deforestation has been curbed in the lowland. It's now limited to areas at the edges of the park.

Sandai

Pawan

Penjawaan

pang Tiga

Kuala Satong

Laman Satong

Laman Satong Customary Forest

Kuala Tolak

Recovering habitat
Forest loss in the park because of illegal logging and drought-driven fires peaked in 1997. Thanks to conservation initiatives and forest protections, much of the degraded area is regenerating.

Morning mist touches down in the lowland rainforest that carpets Mount Palung. The national park contains nine distinct forest habitats, rising in a series of steep slopes from mangroves and peat swamps to mossy mountaintops.

TIM LAMAN, WITH DRONE PILOT TRI WAHYU SUSANTO

Flanked by huge buttresses of the fruiting tree *Dialium,* researchers (from left) Zakaria, Ari Marlina, and Sahril Ramadani watch and collect data on orangutans in the forest canopy. A research initiative, now called the Gunung Palung Orangutan Conservation Program, was established in 1994 and focuses on the apes' habitat and how they respond to fluctuations in their food supply.

invited me to visit the site, and after two days and nights of travel that landed me in West Kalimantan's capital, Pontianak, followed by a flight to Ketapang, a jarring truck ride, and a six-hour hike with two river crossings, I reached the Cabang Panti Research Station in the west-central section of the park.

The rustic compound consists of three wooden buildings that serve as laboratory, workspace, kitchen, and staff living quarters, arranged around a sandy yard on the bank of the Air Putih River. In the woods nearby, a few cabins on stilts house a rotating mix of 20 or so researchers and visiting university students. As a species that's crucial to the vitality of the whole region, orangutans are the main focus, but there are projects focused on other parts of this complex ecological web. I met Endro Setiawan, for example, who is working to create a complete database of Gunung Palung's trees.

After my mission into the forest canopy, I spent the rest of my hours with my feet on the ground, wandering. Like Beccari roughly 160 years ago, I was awed by the seemingly infinite life-forms that make up the forest. I watched red leaf monkeys and macaques scampering to outflank one another in the canopy. Paper kite butterflies the size of my palm fluttered by. I had to stare hard to spot a lime-green pit viper camouflaged on a twig beside the trail. During a breath-stealing dip in the river, I noticed a three-foot monitor lizard hunting for fish and a softshell turtle nosing the bank. Back in the forest, a Wallace's flying frog sprang from a tree—its spindly legs and webbed toes spread-eagle—seeming more bat than amphibian. I delighted in the song of the white-rumped shama, which makes it a prime target for the pet trade, and looked forward to the daily visit of a blue-eared kingfisher, which flew down the river at the same time each evening. And at night I shone my flashlight on patterned tree frogs—pupils dilated, ready to nab any insect that would fit in their mouths—and on lizards and birds asleep on overhanging limbs.

Most nights it rained in torrents. Thunder rolled and boomed. In the morning the river was bloated, its current rampaging. But within hours the water had dropped, having washed into the swamp forest and soaked into the sandy soil. The forest glistened.

One morning I decided to hike a trail that led up 3,500 feet of elevation, through five of the nine forest habitats. Starting near the research station, in the tall, lowland dipterocarp forest, the early going was gentle but soon wound up a steep, mud-slick track. The thick canopy blocked out the light, and the humidity was suffocating. But by noon, I had topped out in the moss-draped montane forest, a land of lichens and ferns and orchids and graced with sunshine. I sat atop a green-carpeted boulder and breathed.

It was lovely there, but I didn't stay long. I still had orangutans on the brain, and the researchers at the station had promised to alert me if they came across any. They'd warned me not to get my hopes up. Orangutans are the only great apes that don't live in large social groups. Since they rely mainly

Rarely seen, little studied, and considered vulnerable to extinction, a Sunda clouded leopard sets off a camera trap near Cabang Panti Research Station. The cats, which are most active at night, have broad paws, flexible hind legs, and long tails that equip them for climbing trees, descending headfirst, and even hanging from branches while gripping their prey. They're known to eat everything from monkeys, deer, and pigs to fish, civets, and porcupines.

on fruit, a crowd would quickly exhaust an area's food supply. So they spread out and can range far from the research station. It might take days of searching to find them. My departure loomed, and I was running out of time.

THE NEXT MORNING, I WAS SIPPING COFFEE MADE candy-sweet with condensed milk, the way locals drink it, when a student hurried to my cabin. A pair of orangutans—a mother and son, known to researchers as Bibi and Bayas—had been spotted a half hour's walk from camp. I shoved my shriveled feet back into perpetually damp socks and boots and grabbed my binoculars.

We found the two apes, with their telltale ginger frizz and bulbous bellies, grazing in the canopy. One by one, they plucked and slurped down *Popowia*, one of the hundreds of fruits they eat. Feeding is an all-day affair, and the apes will move from tree to tree with ease to find what's ripe. Technically, they're frugivores—an average of 60 percent of their diet is fruit—though they'll also eat tree bark, leaves, and insects. But the fruiting cycles of the trees shape their journeys across the forest. The apes, in turn, help shape the forest, seeding new trees as they poop along their travels.

Apparently unaware of the vital service they

In addition to Gunung Palung's roughly 70 mammal species, thousands of other creatures jam-pack the lowland rainforest. Clockwise from above: A Wallace's flying frog has extra-large foot webbing for gliding through the canopy; a trilobite beetle can stay "forever young," remaining in larval form throughout adulthood, possibly to conserve energy for reproduction; a cluster of slug moth caterpillars warns off predators with their stinging bristles; and a praying mantis in dead-leaf camouflage stalks prey such as butterflies, honeybees, and aphids.

provide, mother and son, with their hooded eyes and languid movements, seemed utterly bored with their task. But that was my human bias—perhaps what I was seeing was total orangutan zen. Unlike me, with my previous clunky ascent into the canopy, they casually traveled between trees on those impossibly long arms. Sometimes seven-year-old Bayas would stand on a slender bough and lean out until it bent under his bulk, then ride it to a neighboring trunk. When thunder announced a storm, Bibi, who's estimated to be about 30, displayed her wisdom during a short rain, holding a cluster of leafy limbs over her head like an umbrella. Bayas, a few trees over, just got wet.

I followed their movements until my neck spasmed, until the light dimmed, and with each passing moment, I worried I'd miss something. Finally, Bibi built a nest, as she does most evenings, bending branches to make a platform up high. Bayas joined her, and they settled in for the night.

BEFORE I LEFT GUNUNG PALUNG, ENDRO SETIAWAN OFFERED to give me a very different kind of tour of the lush world around us. We were walking along a trail when the 43-year-old forester stopped and slid a *mandau,* the machete-like knife carried by the Indigenous Dayak people, from a sheath at his waist. Using the shining toothed blade, he nicked a bit of bark from a tree, then tapped, exposing the underbark. "Smell that," he said. I pressed my nose against the wound. It smelled ... earthy? A little sweet. "That is the smell of *Dillenia,"* he said. Then he had me press an ear against the same spot, to hear the tree's song—mildly fizzy, like a lightly sparkling wine.

Here, the soft-spoken Indonesian tree expert was in his happy place, revealing the secrets of the forest he's spent years studying. He and a team of university students from Jakarta and elsewhere were working to identify all the tree species inside 39 research plots for a detailed database. They expected to add hundreds more to the thousand already known. "Plants are the window on the science," he said. "If you know the plants and trees, you know the heart of the park. From there you can learn about everything that relies on them."

I examined, listened to, and smelled a host of trees as we walked. Endro pointed out the grand *Shorea* with its giant buttresses, like the fins on a rocket, that offer stability where underground roots are shallow—common among dipterocarps, the giant hardwood that dominates the forest. Borneo is a hot spot for trees from this family, with some 270 species. He spotted a strangler fig and described how it sprouted from a seed that found purchase in the high crotch of another species, slowly sent roots to the ground, and ultimately choked its host.

He showed me the stump of a Borneo ironwood—a victim of loggers. The evergreen produces a dense, heavy wood locally cherished but prized by builders. This tree, he noted, could have topped 150 feet and lived a thousand years.

Endro explained how every three to five years or so, the forest experiences a phenomenon called mast fruiting, when trees suddenly produce a superabundance of fruit and attract

The Atlas moth, one of thousands of moth species in Borneo and a beguiling resident of Gunung Palung, is supersize among lepidopterans, with a wingspan up to 10 inches. Its upper wing tips resemble outward-facing snake heads when popped open, possibly to startle predators. Some moth species rely on specific plants to host them throughout their lives, making forest diversity essential to the insects' survival.

large amounts of wildlife. Though the fruit supply at the moment was modest, fruiting species abounded, including 56 species of fig trees alone.

As we explored, I pestered Endro for the names of the trees we passed. There were *Dipterocarpus,* and *Shorea, Hopea* and *Vatica, Monocarpia* and *Melanochyla*—an endless stream of Latin names. I gave up trying to remember them all and just followed him, soaking it all in.

The lessons continued, and a pattern emerged: The trees offer nourishment to the orangutans—as well as to the other mammals, birds, reptiles, amphibians, insects, fungi, and microbes—but for many, the trees also provide structure, a calendar of the seasons, a transport system. For others, a playground, a school, shelter. For all, a place to lay their heads. A home.

Days earlier, on that climb into the canopy, I'd hoped the wildness of the place would burst forth in animal form. But now it was obvious I'd been immersed in something more profound—the cradle of everything that lives here. As Endro helped me see: What could be more important, more glorious, than the habitat that makes it all possible? ▯

Longtime contributor **Jennifer S. Holland** is the author of the book *Dog Smart: Life-Changing Lessons in Canine Intelligence,* publishing in May.

The Milky Way comes into view through a gap in the canopy. Borneo's rainforests are millions of years old and among the most biologically diverse on Earth, a resilient home for thousands of species found only there. The hope is that humans allow them to flourish far into the future.

A recently weaned harp seal pup swims in the Gulf of St. Lawrence. Female harp seals give birth on ice. For two weeks, pups build up fat reserves, enabling them to be weaned from their mothers, to withstand frigid waters, and to survive on their own.

ON THE ICE

SCIENTIST TURNED PHOTOGRAPHER JENNIFER HAYES HAS BEEN DOCUMENTING HARP SEAL BIRTHS IN THE NORTHWEST ATLANTIC FOR MORE THAN A DECADE. IN THIS ESSAY, SHE REFLECTS ON THE PUPS' BATTLE FOR SURVIVAL AS WINTERS GET WARMER.

Mothers and pups lie scattered across fractured ice in the gulf in late February 2020. As temperatures warmed and winds blew, the ice—stained with blood from birth—continued to break up.

DIVING

beneath a white cathedral of ice, I could hear the shrill whistles, honks, and squeaks of harp seals.

They could easily have been mistaken for the sounds of a rainforest—except I was in the frigid waters of the Gulf of St. Lawrence. Around me, adult harp seals gracefully soared through their private underworld. On a ceiling of ice above us rested thousands of newborn pups.

I was in the Magdalen Islands, an archipelago in the gulf, in March 2011. Together with my partner, David Doubilet, I had set out to photograph harp seals as part of a comprehensive story on the marine ecosystem of the Gulf of St. Lawrence—an alcove of the North Atlantic Ocean—where the waters teem with life. Historically in winter, the gulf's pack ice transforms into the southernmost whelping grounds for harp seals—an ice nursery for newborn pups.

"Come, we search for ice," said Mario Cyr, our local guide. "If we find ice, we find seals." He was right: A herd of pregnant females had located a loose patchwork of ice near Prince Edward Island, hauled out, and given birth. Our boat navigated into the ice, and we spent a week documenting harp seal behavior above and below the surface. The seal herd was spread among a windswept puzzle of small pans of ice surrounded by semifrozen slush. By day, the sun danced across an icescape dotted with harp seal mothers and pups with cloud-soft fur, obsidian eyes, and charcoal noses. At night a chorus of infant-like cries from the pups wafted through the hull of our boat as we slept.

Harp seals need to give birth on ice. Migrating from the Arctic at the end of August, they will search for sea ice in late February, when typically each pregnant female gives birth to a single pup. Mothers will nurse their young for the first two weeks of life, building up their fat reserves, and then abandon them on the ice when they leave to mate. The pups

A harp seal pup, its ultimate fate unknown, is caught between shifting ice pans after a storm in March 2022 struck off the coast of Newfoundland and Labrador, in an area called the Front. Heavy rain and high winds can lead to deadly results for pups whose survival depends on ice.

A mother and her pup greet each other with a "kiss" of recognition in 2011. In a herd of fluffy white pups, mothers identify their young by touching noses to determine scent. While nursing, pups occasionally slip off their ice pan; they cannot survive in the water for long.

FRAGILE HABITAT

Beginning in late August, Northwest Atlantic harp seals begin a monthslong migration from Greenland and the Canadian Arctic to as far south as the Gulf of St. Lawrence to give birth, or whelp, on sea ice. But a warming climate is making the ice thinner—and more hazardous for their pups.

In March 2011, a mother and pup relax after nursing. Pupping season in Québec's Magdalen Islands has become a draw for international tourists. But unstable ice during recent winters has led to catastrophic drowning rates among newborn harp seals. Now each February brings apprehension for tour operators.

rely on their blubber to survive until they master swimming and how to capture their own food. To learn how to be a harp seal, the pups need time—and stable ice.

But winters in the Gulf of St. Lawrence are warming twice as fast as summers, at a pace of more than two degrees Celsius every hundred years, says Peter Galbraith, research scientist in physical oceanography at Fisheries and Oceans Canada (DFO). This means diminished sea ice cover and vanishing nursery options for pregnant harp seals in the gulf.

Scientists tend to talk about winters in the region as good ice years and bad ice years. Good ice years—characterized by colder winters and thick, wide-reaching ice cover—are becoming less frequent: Sea ice in the gulf has been deteriorating since at least 1995. More common now are bad ice years, triggered by mild winters that produce fragile, thin ice pans prone to collapse. Bad ice years can be devastating for harp seals. One of those was 2011.

On our last day in the gulf that March, a storm tore across the water, whipping it to froth and frenzy. We had made it to harbor and were off-loading our gear when Cyr gave us the news:

KATIE ARMSTRONG, NGM STAFF. SOURCES: GARRY STENSON; PETER GALBRAITH, FISHERIES AND OCEANS CANADA; 2021 OCEANOGRAPHIC DATA, NORTHWEST ATLANTIC FISHERIES ORGANIZATION; IUCN; NSIDC

In a helicopter above the Front in March 2022, scientists Jessica Foley and Garry Stenson of Fisheries and Oceans Canada survey the harp seal population (top). An unusually aggressive male harp seal (above, at left) attempts to mate with a nonreceptive female, whose pup sits nearby. Mating season follows after mothers have weaned their young. A pup struggles on thin ice in 2020 (right). Historically, thick sea ice cover in the gulf offered a safe and reliable place for pups to survive.

The weak ice, around which we'd spent days immersed in the lives of harp seals, had been pulverized by the storm. Thousands of pups had perished. In an instant, the nursery became a memory that existed only in our pictures.

The pups' deaths were a crystallizing moment for me—when climate change came frighteningly into focus, playing out in real time. As a scientist turned storyteller, I questioned what the future held for this species that requires ice to survive. On my drive home, I became intent on documenting harp seals as a face of the climate crisis and have returned to the gulf's pupping grounds over and over again for the past decade.

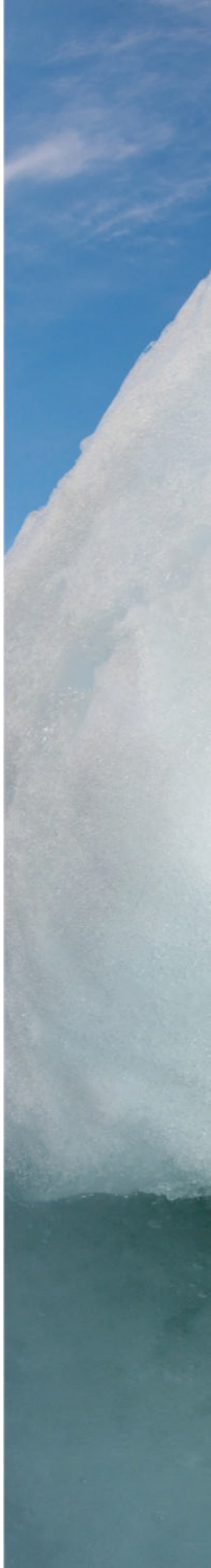
What I've learned since from Garry Stenson and Mike Hammill, harp seal experts at the DFO: Having no ice in the Gulf of St. Lawrence may be better than poor ice. In its absence, harp seals swim farther and seek ice outside their traditional pupping grounds. But, they agree, if there is any ice at all, no matter how bad, the herd will stay and use it, even if it's too thin to sustain pups. But as harp seals move north to colder, icier habitats, such as off Baffin Island, they may face a new threat: polar bears.

In March 2022, I joined Stenson and a large team aboard the Canadian Coast Guard ship *Sir William Alexander.* They were in the middle of a harp seal survey conducted every four to five years at an area called the Front, off the coast of Newfoundland and Labrador—the largest whelping ground for the Northwest Atlantic harp seal population by area and number of seals.

'ICE IS POORER, THE WINDS ARE STRONGER, AND THE CHALLENGES ARE GREATER.'
—GARRY STENSON, RESEARCH SCIENTIST

The coordinated efforts to survey the area require fixed-wing aircraft and ship-based helicopters. Beacons deployed in the seal patches help aerial surveyors count pups, assess their age, and track movement. It's hard enough in a good year. But each survey is getting a little more difficult, says Stenson. The sea ice off Newfoundland and Labrador is slowly trending in a similar direction as ice in the Gulf of St. Lawrence. Early in the survey, a severe storm blew the ice offshore and broke it up as winds pushed surviving pups eastward, away from usual foraging areas. It was Stenson's last survey before his retirement and his most challenging yet: "The ice is poorer, the winds are stronger, and the challenges are greater."

As grim as the outlook seems to be, there is some hope. Harp seals can adapt, and to survive, they will follow the ice. Long term, Hammill and Stenson predict, seals may establish whelping grounds farther north. This month the seals will begin another pupping season in the Gulf of St. Lawrence. I'll be there waiting—and hoping for good ice. ▯



A pup hunkers down to shelter from relentless winds in March 2012. Scientists say that as long as there is sea ice, no matter how frail, harp seals will continue to risk giving birth in their traditional whelping grounds.

INSTAGRAM

SPENCER LOWELL

FROM OUR PHOTOGRAPHERS

WHO

A California-based photographer who focuses on space and technology

WHERE

Hat Creek, California

WHAT

Phase One XF camera with a 50mm lens

While on assignment for a story about the search for extraterrestrial life, Lowell visited the Allen Telescope Array. The 42 radio dishes in Northern California collectively form a single telescope that scans broad sections of the sky at multiple wavelengths to identify possible signals from technologically advanced life-forms on distant exoplanets. Lowell captured a technician servicing one of the instruments. With only the man's legs visible, Lowell says, it looked like he too "was actively searching for something."

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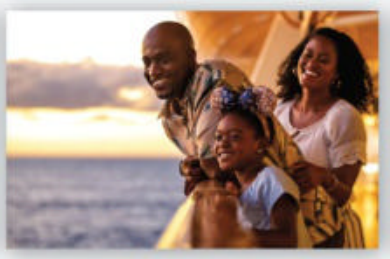
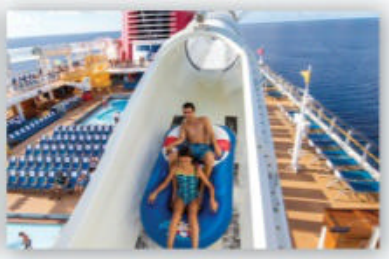

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